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(NASA-CR-172695) SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY Final Executive Summary Report (Rockwell International Corp., Downey, Calif.) 102 p HC A06/MF A01 CSCL 22B G3/15
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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY

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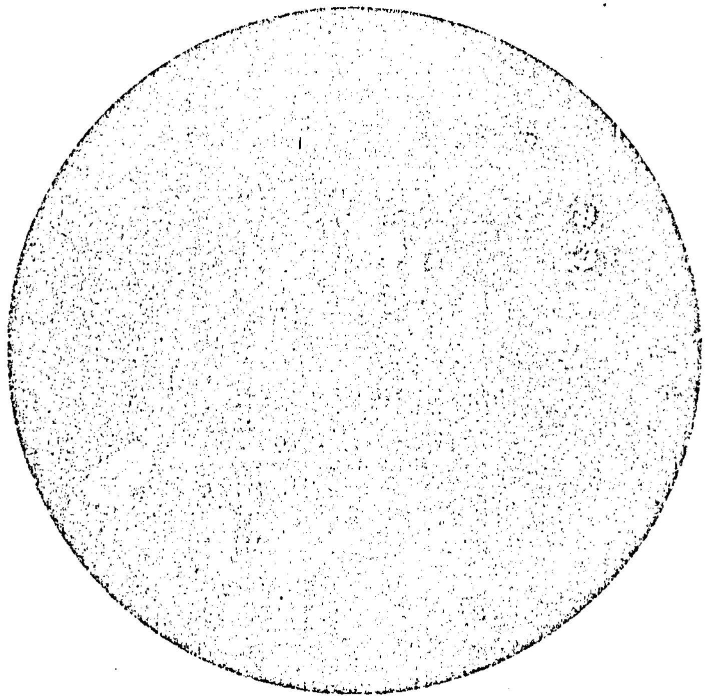

FINAL EXECUTIVE SUMMARY REPORT

APRIL 22, 1983

CONTRACT NASW 3633

Rockwell International

Shuttle Integration &
Satellite Systems Division
Rockwell International Corporation
12214 Lakewood Boulevard
Downey, California 90241

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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY

FINAL EXECUTIVE SUMMARY REPORT

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CONTRACT NASW 3683

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FOREWORD

The Space Station Needs, Attributes, and Architectural Options Study contract (NASW 3683) was conducted by the Rockwell Shuttle Integration and Satellite Systems Division for NASA.

The final report summarizes the results of this study in five volumes, which are:

- Final Executive Summary Report
- Missions and Requirements
- Program Options, Architecture, and Technology
- Cost and Benefits
- DOD Task

Any questions regarding this final report should be directed to G.M. Hanley, study manager, at (213) 922-0215.

SUMMARY BRIEFING OUTLINE ...

RECOMMENDED PROGRAM ARCHITECTURE

MISSIONS AND REQUIREMENTS

PROGRAMMATIC EVOLUTION

SPACE STATION ARCHITECTURE, TECHNOLOGY, AND COST

SPACE STATION ATTRIBUTES AND BENEFITS

CONCLUSIONS

RECOMMENDED SPACE SUPPORT SYSTEM PROGRAM ARCHITECTURE

This chart summarizes the top-level, time-phased total space program support system architecture that was recommended as a result of this study.

The Space Shuttle will play a key role in the early development of orbital operational techniques and orbital transfer vehicle (OTV) and teleoperator maneuvering system (TMS) space-based technology. The Shuttle will also be important in the initial development of commercial space processing and, in this role, will require extended durations. As the station becomes available, the only major change to the Shuttle is the possible capability for propellant scavenging from the external tank (ET) and/or from the Shuttle main propulsion subsystem (MPS).

Along with a space-based TMS, an initial four-man station will have capabilities for low earth orbit (LEO) placement and retrieval, station attached and integral mission payloads, storage, and LEO servicing. This station is located at a 28-degree inclination and 200 nmi altitude. Free flyers and the multimission spacecraft (MMS) can support mission payload needs in the vicinity of the station.

An evolutionary Space Station and a space-based OTV are introduced in 1994. The evolutionary Space Station may be the initial Space Station with growth to eight men and with mission capabilities that include initial capabilities and OTV high energy orbit (HEO) payload placement and servicing, assembly, and construction of mission payloads. As an option, two four-man Space Stations co-orbiting at 28 degrees may be desirable to split the potentially incompatible functions of research and development (R&D) and operations.

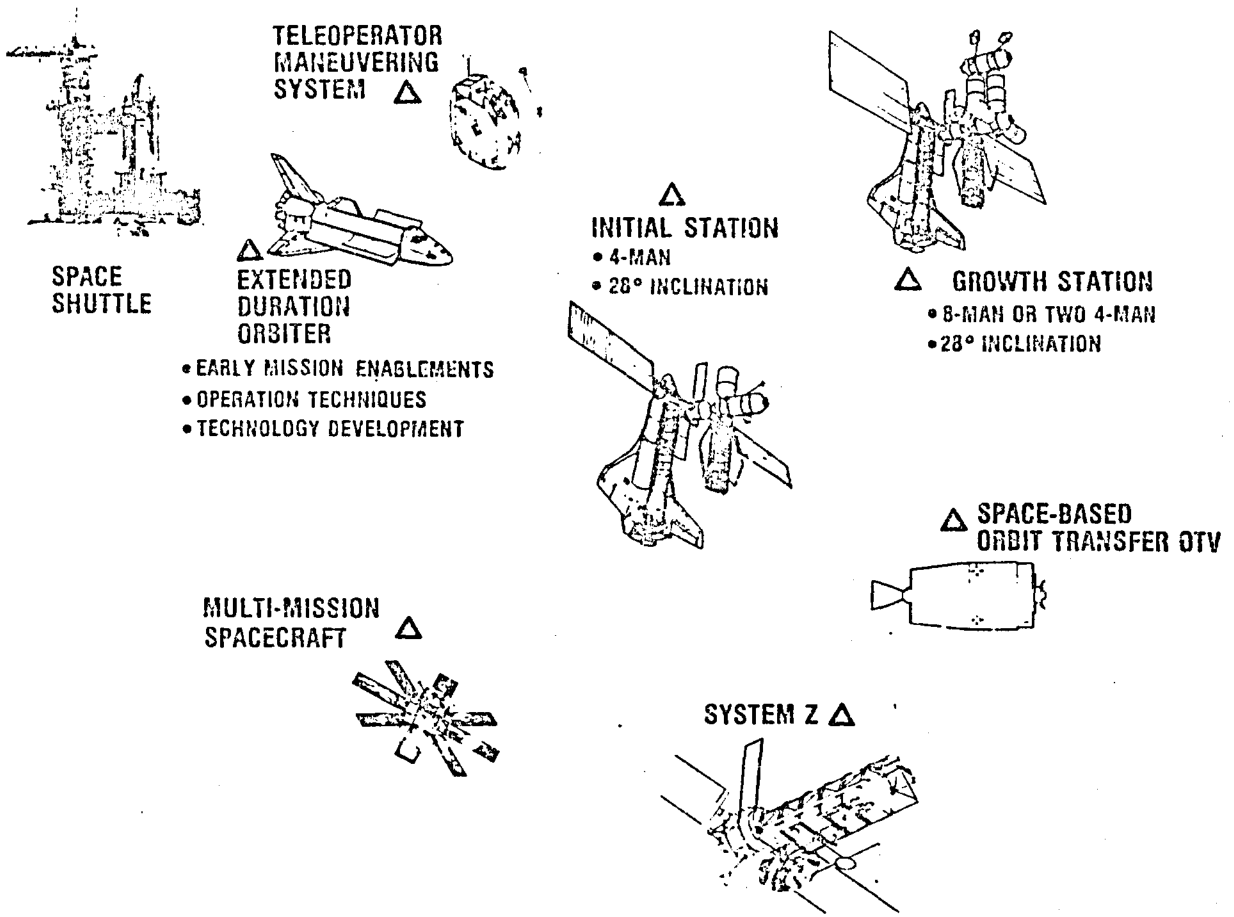
System Z, proposed by the Jet Propulsion Laboratory (JPL) and Goddard for earth observation missions in high inclination orbit, is accommodated in 1993 using a Space Station derivative platform.

SPACE STATION

RECOMMENDED SPACE SUPPORT SYSTEM PROGRAM ARCHITECTURE ...

1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000

GROUND-BASED △ △ LEO STATION-BASED △ GEO-BASED



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SUMMARY BRIEFING OUTLINE ...

RECOMMENDED PROGRAM ARCHITECTURE

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MISSION, SERVICES, AND SUPPORT SYSTEM MATRIX

Space support subsystems provide the services needed by mission payloads. The requirements were developed by determining the services required by the mission payloads. These services are provided by potential alternative support subsystems dependent upon their availability and the orbital service location. Requirements for a support subsystem are determined by the frequency of the services (derived from the mission model) and the time-phased resource demands of the services. Total requirements are determined by adding the requirement of the support subsystem itself to the mission services requirement. Resources include man-hours, power and heat rejection, data, attitude control, g-level, volume, attachment ports, and length of a linear payload retention facility.

The following charts summarize the mission model, the systems providing the support, and the time-phased requirements imposed on the Space Station.

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SPACE STATION

MISSION, SERVICES, AND SUPPORT SYSTEM MATRIX ...

ALTERNATIVE SUPPORT SYSTEMS

- EXPENDABLE LVs
- SHUTTLE
- HLLV
- EXPENDABLE UPPER STAGES
- REUSABLE OTVs
- SPACE STATION
- FREE FLYER S/C
- SPACE PLATFORM
- TMS

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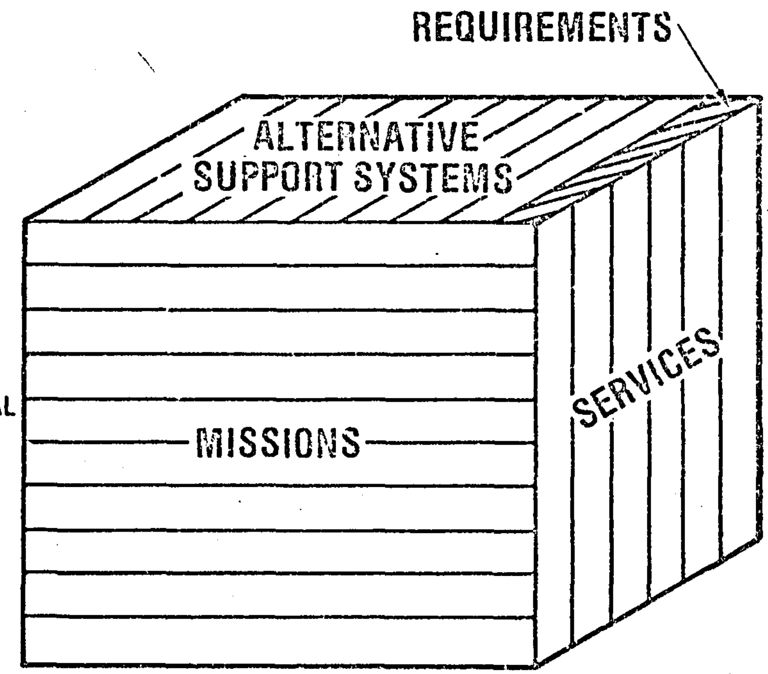

MISSION AREAS

- NASA SCI & APPL
- NASA TECHNOLOGY DEV
- GOVERNMENT ENVIRONMENTAL
- DOD
- COMMERCIAL COMM
- COMMERCIAL SPACE PROC
- COMMERCIAL RESOURCES

SERVICES

- LEO PLACEMENT
- LEO SERVICING
- LEO RETRIEVAL
- HEO PLACEMENT
- HEO SERVICING
- ATTACHED P/L
- INTEGRAL P/L
- CHECK-OUT
- DEPLOYMENT
- ASSEMBLY/CONSTR
- STORAGE

MISSION MODEL LEVEL PHILOSOPHY (1991-2000)

This chart summarizes the philosophy behind the low, medium, and high mission models for each of the mission areas. It also shows the total number of mission payloads and their masses. The masses are the size of the payloads as delivered by the transportation system to their operational orbits. To determine total mass in the Shuttle, other masses need to be added. These include airborne support equipment (ASE) mass, propellant and stage masses, and space support subsystem masses.

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SPACE STATION

MISSION MODEL LEVEL PHILOSOPHY... (1991-2000)

MISSION AREA	LOW	MEDIUM	HIGH
SCIENCE AND APPLICATIONS	• SHARED LIFE SCIENCES FACILITIES • AUSTERE PLANETARY PROGRAM • LIMITED OBSERVATION RESEARCH • VIGOROUS ASTROPHYSICS PROGRAM • 143 MISSIONS • 540 KLB MASS	• DEDICATED LIFE SCIENCES MODULE • PLANETARY SAMPLE RETURN • SYSTEM Z • GEO SERVICING • 184 MISSIONS • 640 KLB MASS	• EARLIER LIFE SCIENCE RESEARCH — • 187 MISSIONS • 670 KLB MASS
TECHNOLOGY DEVELOPMENT	• PROGRAMS MADE TO FIT WITHIN AUSTERE LIMITS — SCHEDULES STRETCHED • 15 MISSIONS • 48 KLB MASS	• EMPHASIS ON "MAN-IN-STREET" BENEFITS • OTHER PROGRAMS STRETCHED OUT • 18 MISSIONS • 90 KLB MASS	• FUTURE MAJOR SPACE INITIATIVES SUPPORTED WITH REASONABLE SCHEDULE • 22 MISSIONS • 105 KLB MASS
DOD	• BUSINESS AS USUAL • DOD-SUPPLIED MISSION MODEL + 4 SPECIAL MISSIONS • 153 MISSIONS • 1182 KLB MASS	• MAKE SPACE ASSETS ENDURING (SURVIVABLE) • LEO STORAGE & SELECTIVE SERVICING • 233 MISSIONS • 2450 KLB MASS	• MOVE STRATEGIC & TACTICAL OPERATIONS INTO SPACE • MEDIUM + DEFENSE & ADVANCED RADAR SYSTEMS • 333 MISSIONS • 4890 KLB MASS
COMMERCIAL COMMUNICATIONS	• EXTRAPOLATION OF CURRENT USERS • LOW CAPTURE BY STS AND SP STN • 3 NEW USERS/YR • 105 MISSIONS • 350 KLB MASS	• MOST LIKELY CAPTURE BY STS & SP STN • 4 NEW USERS/YR • MULTI-USER SYSTEMS • 153 MISSIONS • 526 KLB MASS	• STS & SP STN VERY COMPETITIVE vs ELV s • 5 NEW USERS/YR • MORE MULTI-USER SYSTEMS • 233 MISSIONS • 850 KLB MASS
COMMERCIAL SPACE PROCESSING	• PESSIMISTIC MARKET • 9 PRODUCTS • CONSTRAINED RESEARCH • 314 MISSIONS • 440 KLB MASS	• MEETS MOST LIKELY MARKET DEMAND • 15 PRODUCTS • RESEARCH 2 X LOW • 407 MISSIONS • 645 KLB MASS	• MEETS OPTIMISTIC MARKET • 23 PRODUCTS • RESEARCH 3 X LOW • 524 MISSIONS • 830 KLB MASS
TOTAL MISSIONS TOTAL MISSION MASS	731 2550 KLB	981 4440 KLB	1285 7430 KLB

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MISSION LOCATIONS AND MASS FLOWS--MEDIUM MISSION MODEL

This chart summarizes where the missions in the medium mission model are located, in terms of inclination and altitude. Three regions are identified to classify location: (A) low inclination, (B) medium inclination, and (C) high inclination. Within these regions, LEO and HEO are used to define their general altitude locations.

The table shows that the most predominant location for missions, total mass to orbit, and crew hours is the low inclination location. This suggests that this may be the best location for a Space Station to provide services to mission payloads either residing in this location or passing through on their way to high energy orbits. Mission analyses have indicated that a Space Station located at a 28-degree inclination and a 200 nmi altitude can provide a wide variety of services, which are discussed on the next chart. These analyses also show that it is possible and cost-effective to do most of the medium inclination payload placements through the Space Station, thus increasing the capture capability of the Space Station.

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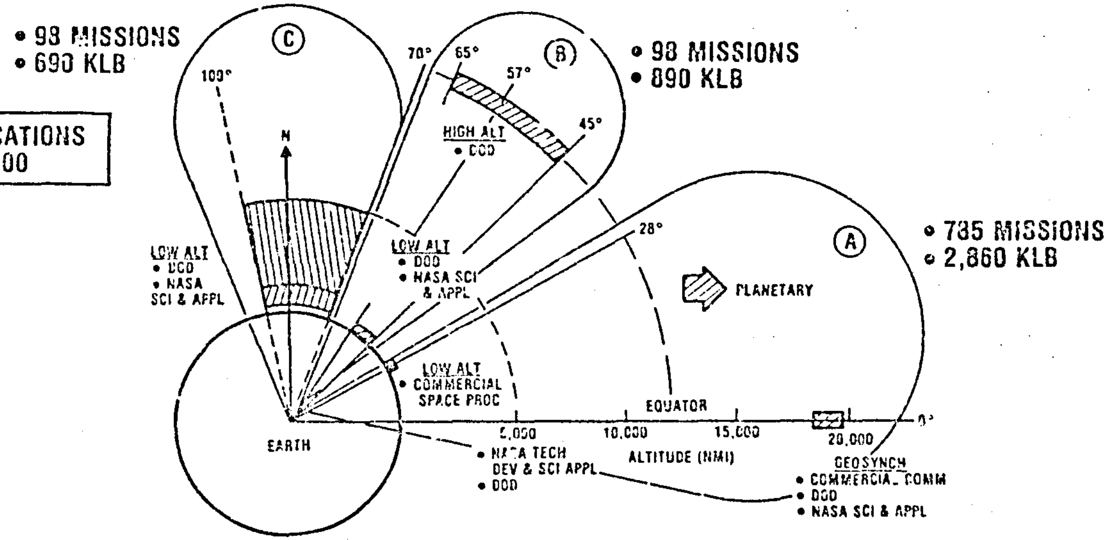
SPACE STATION

MISSION LOCATIONS AND MASS FLOWS — MEDIUM MISSION MODEL ...

MISSION LOCATIONS 1991-2000



* MASS FLOW THROUGH REGIONS — 1991-2000

LOCATION	NO. OF MISSIONS	MISSION MASS (MILLIONS OF LB)	PROPELLANT MASS (MILLIONS OF LB)	OTHER SYST MASS (MILLIONS OF LB)	TOTAL CARGO MASS (MILLIONS OF LB)	CREW HOURS
A	848	3.9	3.0	5.4	11.4	149,500
B	35	0.8	—	—	0.8	200
C	98	0.7	—	0.6	1.3	3,700
TOTAL	981	5	3.0	6.0	13.5	153,400

*ASSUMES SPACE STATION AT 28.5° INCLINATION

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SELECTED ACCOMMODATION MODES AND SPACE STATION ACCOMMODATION OF MISSIONS

The next two charts summarize the manner in which the mission services desired by the mission payloads are provided for each inclination region. It is assumed that the Space Station is located at a 28-degree inclination and a 200 nmi altitude. The Space Station would probably not have all of the services listed initially; therefore, this accommodation description applies to the evolutionary Space Station.

The geometry of mission payloads that are on free flyers near the station fall into two general categories. One category is those that essentially co-orbit with the Space Station. These payloads include the space processing free flyers, which desire frequent harvesting of products. The other category is NASA Science and Application free flyers and DOD-stored payloads that would need servicing infrequently (one year or greater). These satellites are located at a higher altitude than the station and, although they are also in a 28-degree inclination, their orbital plane aligns with the station orbital plane about once a year to allow servicing, if desired.

All low inclination placement missions for LEO and HEO go through the Space Station. The LEO payloads are placed in their mission locations by the TMS, which is space-based at the station. HEO payloads are placed in their mission locations using an OTV, which is also space-based at the Space Station. LEO medium inclination payloads are delivered directly by the Shuttle or by the Shuttle and TMS. HEO medium inclination payloads are delivered to their mission orbits through the Space Station using the OTV. Mission analysis studies have shown this to be the best mode.

No high energy missions exist at high inclination. LEO missions in this region (placement, servicing, and retrieval) are accomplished by the Shuttle or the Shuttle and TMS.

Servicing at LEO and low inclination of the two streams of satellites in the vicinity of the station is accomplished using the TMS in a remote servicing mode. The Shuttle or Shuttle/TMS are used to conduct servicing at LEO in medium inclination orbits. The only HEO servicing currently planned occurs at geosynchronous orbit (certain DOD payloads and communication satellites). These missions are accomplished using a TMS that is based at geosynchronous orbit (GEO). The station-based OTV delivers propellants and other servicing payloads to the TMS. Obviously, the GEO TMS is of a somewhat different design than the LEO TMS.

Some of the Science and Applications missions and all of the pharmaceutical electrophoresis process missions are flown on the multimission spacecraft (MMS). Station-attached or integral missions include life sciences, pharmaceutical electro-focusing process and crystal growth production, space processing research (NASA and industry), and sortie pallet missions. System Z (sun synchronous orbit) uses a power platform that is a derivative of the Space Station power module and payload support module.

The large 12,000-pounds communications satellites are assembled at the station, deployed, and checked out prior to OTV launch to GEO. Deployment and checkout of some smaller communication satellites also occurs prior to launch.

Propellant storage at the station is extremely important in decoupling the mission payloads, upper stages, and propellants in the Shuttle manifest. This allows Shuttle cargo load factors approaching 1.0 rather than 0.65, which is experienced without this capability.

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SELECTED ACCOMMODATION MODES...

USER SERVICES	SELECTED ACCOMMODATION MODE — INCLINATION REGION: 28°	57°	POLAR
• LEO PLACEMENT	STATION / TMS	SHUTTLE / TMS	SHUTTLE / TMS
• LEO SERVICING	STATION / TMS	SHUTTLE / TMS	SHUTTLE / TMS
• LEO RETRIEVAL	STATION / TMS	SHUTTLE / TMS	SHUTTLE / TMS
• HEO PLACEMENT	STATION / OTV	STATION / OTV	—
• HEO SERVICING	STATION / OTV / TMS	—	—
• ATTACHED P/L	STATION / MMS	—	MMS / SYSTEM Z PLATFORM
• INTEGRAL P/L	STATION	—	—
• CHECKOUT	STATION	SHUTTLE	—
• DEPLOYMENT	STATION	SHUTTLE	—
• ASSEMBLY / CONSTR	STATION	—	—
• STORAGE	STATION	—	—

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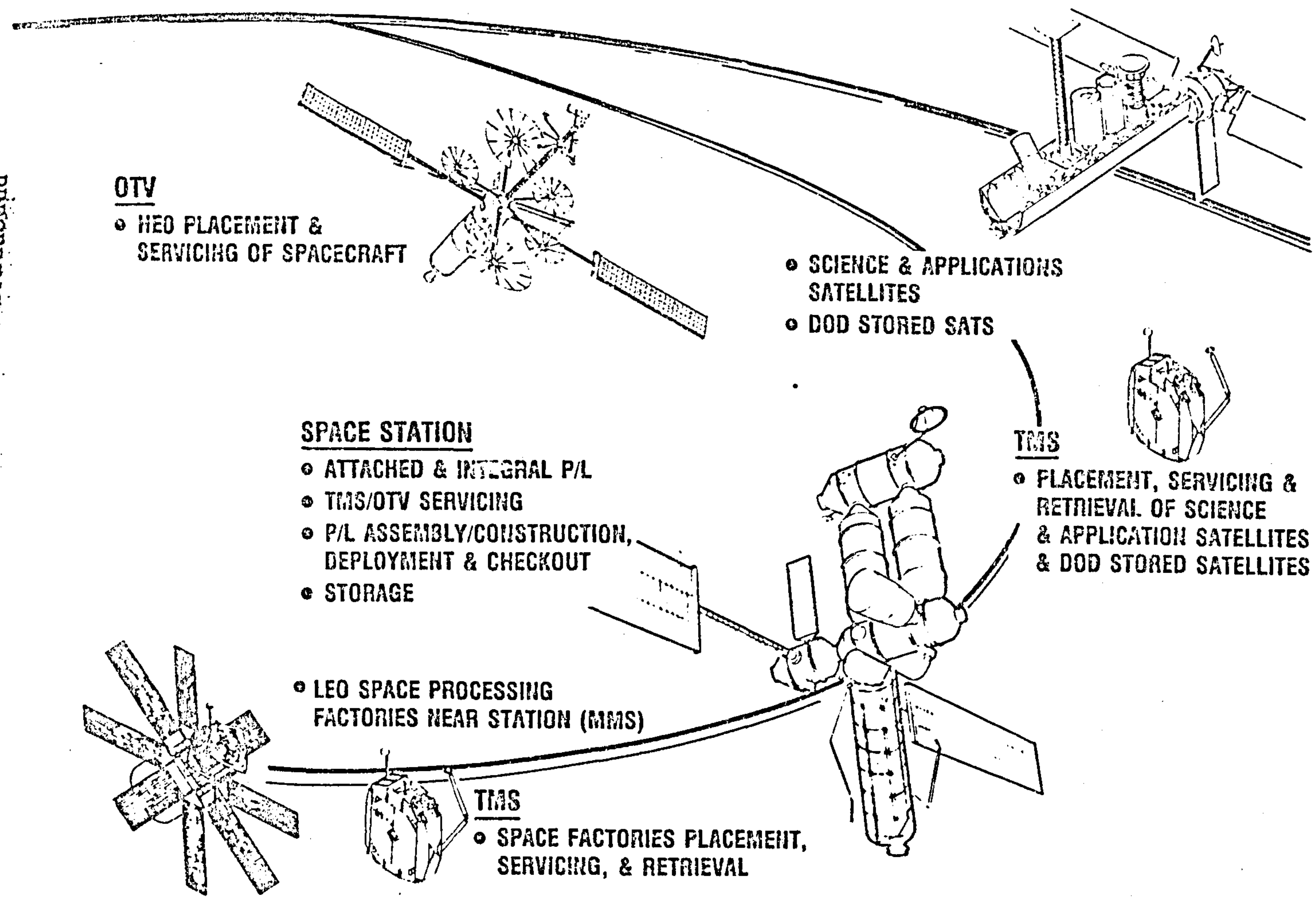
SPACE STATION

SPACE STATION ACCOMMODATION OF MISSIONS . . .



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TIME-PHASED SPACE STATION REQUIREMENTS

The following series of charts summarize the key Space Station requirements for the crew, power, payload service assembly, mission payload mass, user propellant requirements, and data.

An initial four-man crew provides sufficient capability during the first three years to meet the station and payload processing requirements. Growth to an eight-man capability in 1984 provides ample crew to meet the same requirements. The major requirements for man-hours arise from space processing, which also has the least mass flow through the station.

Power capability of the station is shown as end-of-life power. For this reason, the initial station has sufficient power to meet the integrated requirement. The growth station also has sufficient capability with 50 kW at the bus.

Requirements for the payload service assembly (PSA) indicate a maximum of about 810 feet-days for an entire year. The PSA design is about 43 feet in length and provides 15,600 feet-days in a year.

Both the TMS and OTV require propellants at the station in their space-based mode. The bipropellant requirements for the TMS are small compared to the LO_2/LH_2 requirement of the OTV. The OTV requires about 460 pounds of propellant in the peak year.

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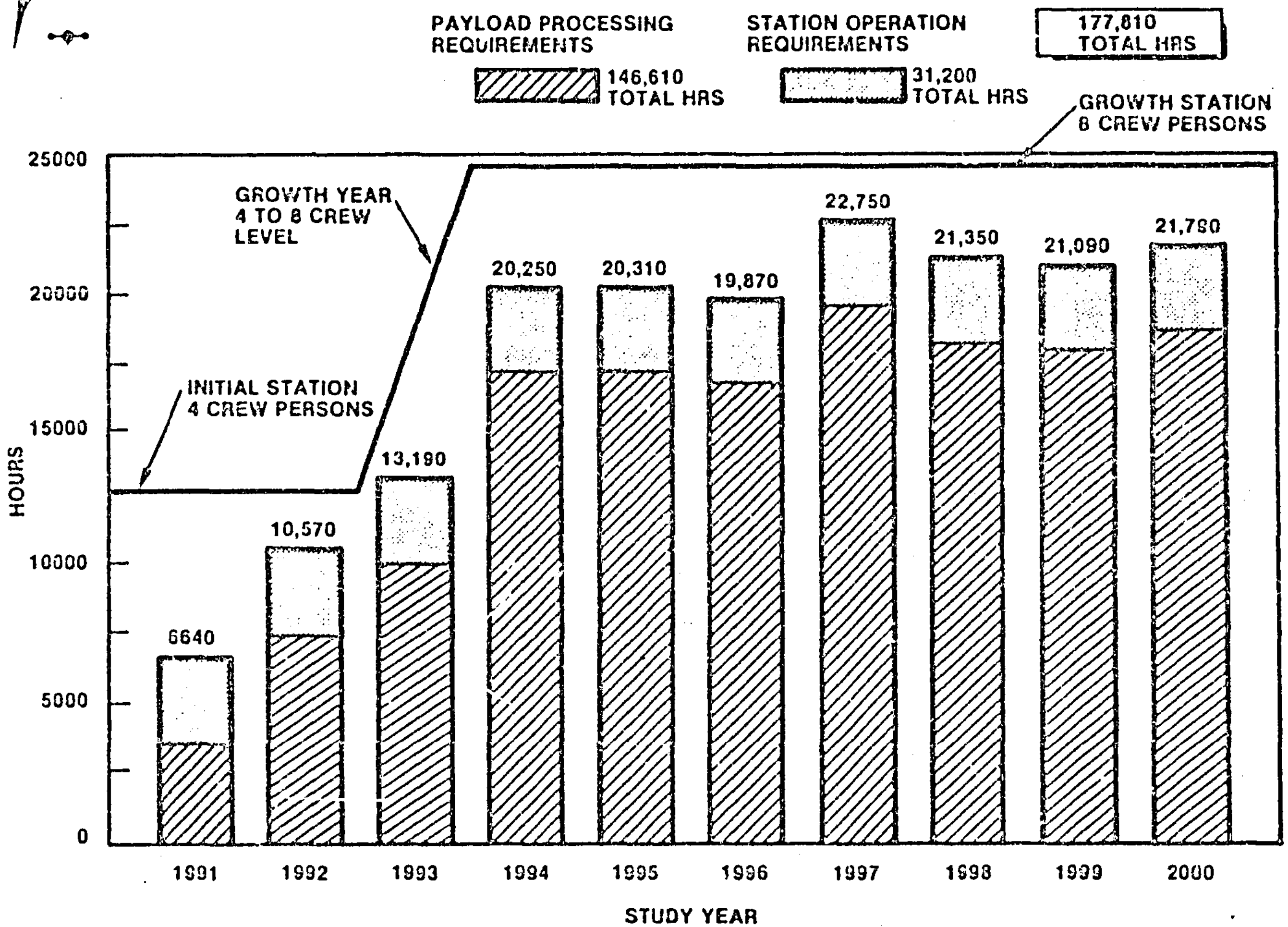
INTEGRATED CREWHOURS REQUIREMENTS...



MEDIUM TRAFFIC MODEL

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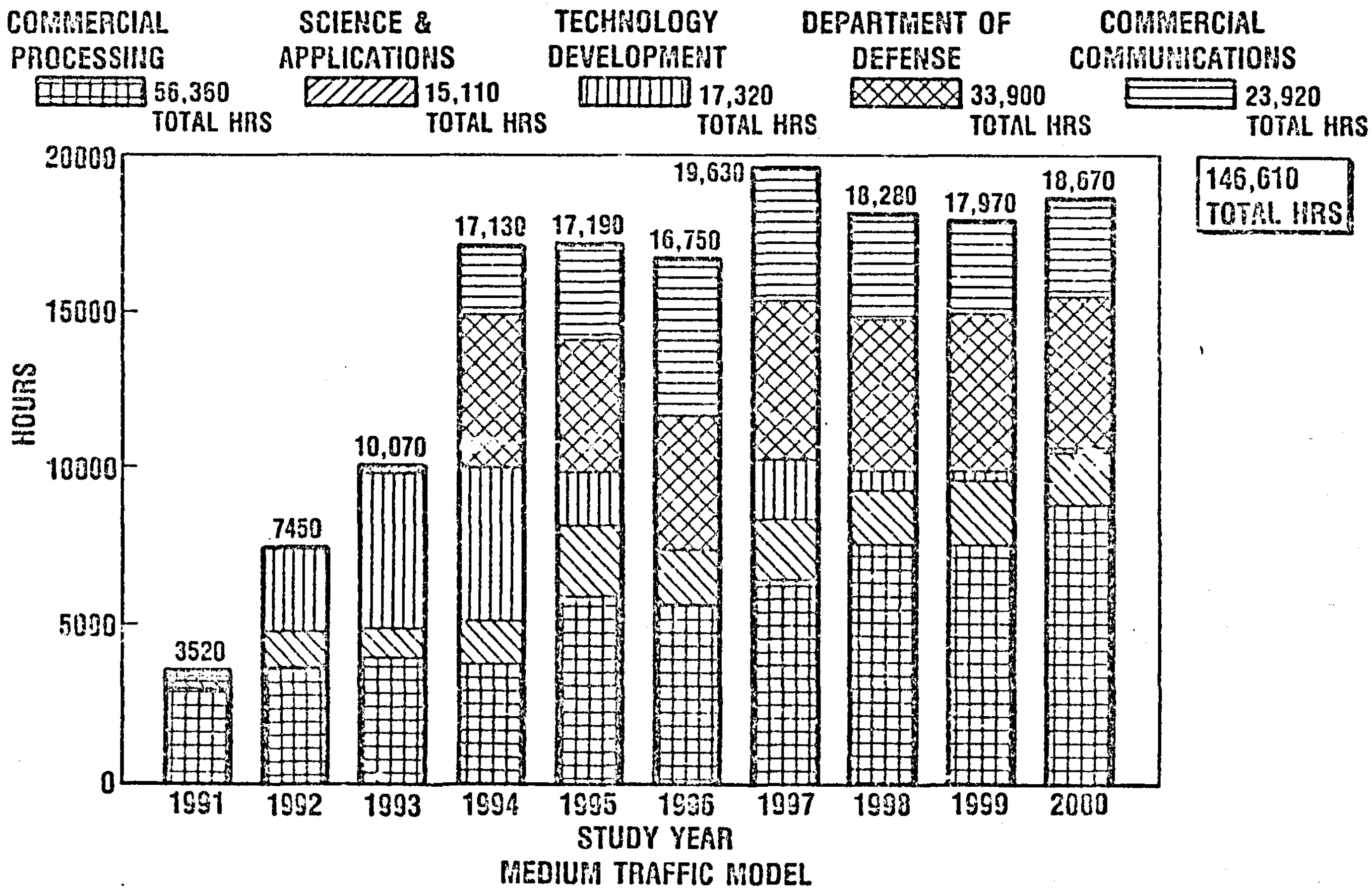
SPACE STATION

USER MISSION PAYLOAD CREWHOURS . . .



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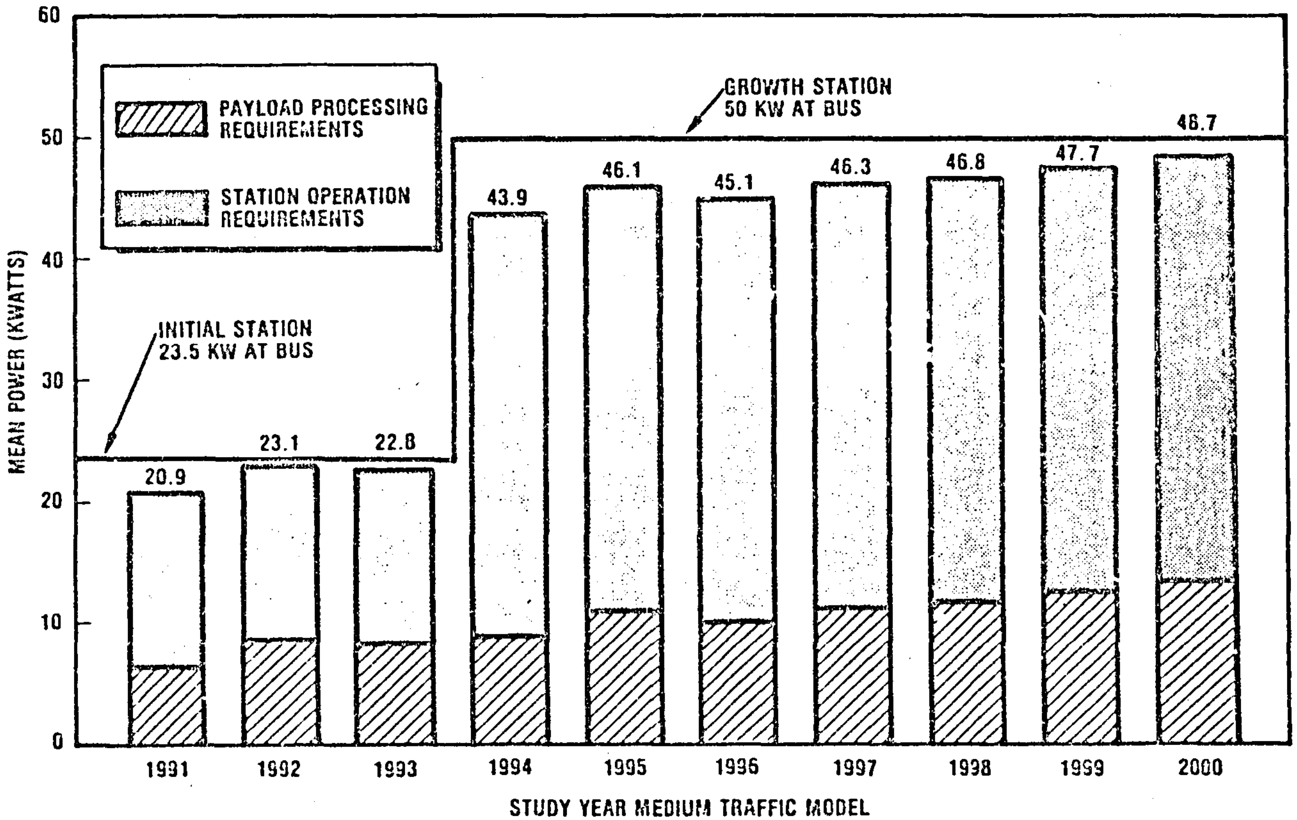
SPACE STATION

INTEGRATED POWER REQUIREMENTS...



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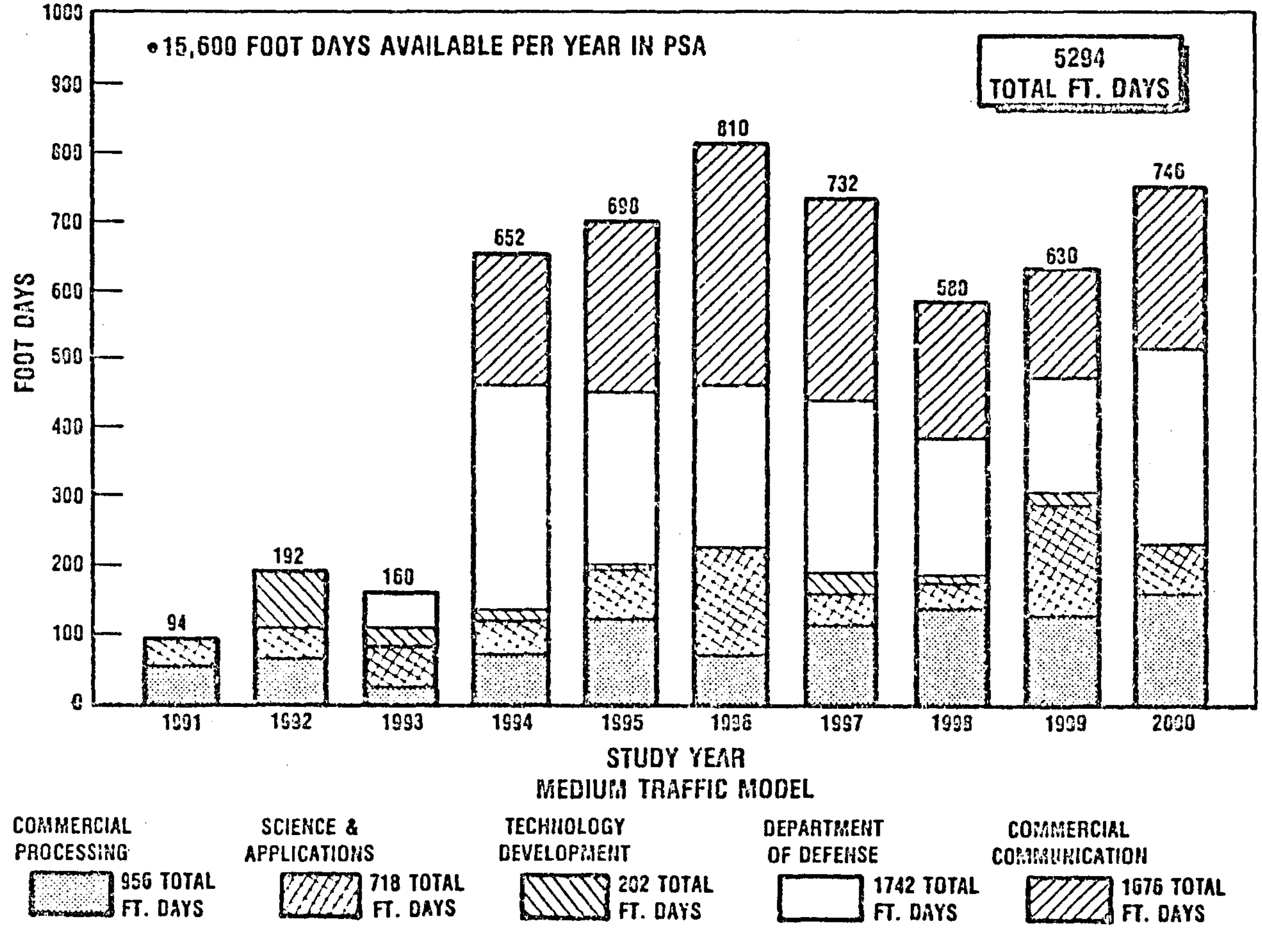
SPACE STATION

PAYLOAD SERVICE ASSEMBLY REQUIREMENTS . . .



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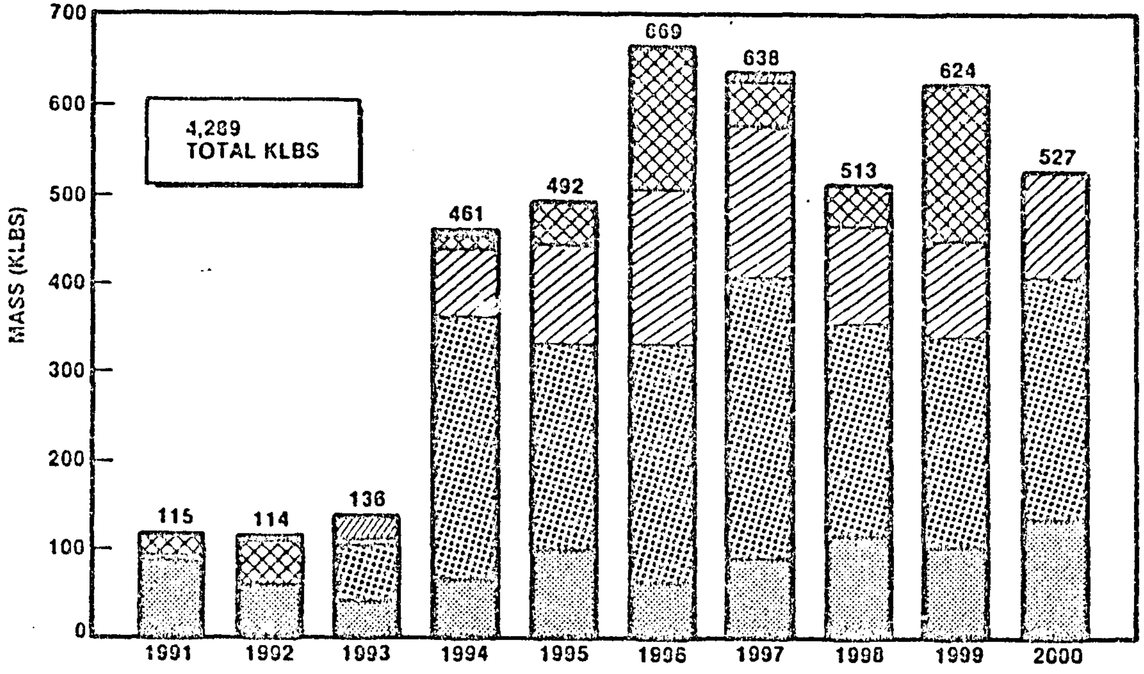
SPACE STATION

USER MISSION PAYLOAD MASS PROCESSED...

COMMERCIAL PROCESSING 851 TOTAL KLBS
DEPARTMENT OF DEFENSE 1,932 TOTAL KLBS
COMMERCIAL COMMUNICATION 680 TOTAL KLBS
SCIENCE AND APPLICATIONS 572 TOTAL KLBS
TECHNOLOGY DEVELOPMENT 54 TOTAL KLBS



MEDIUM TRAFFIC MODEL

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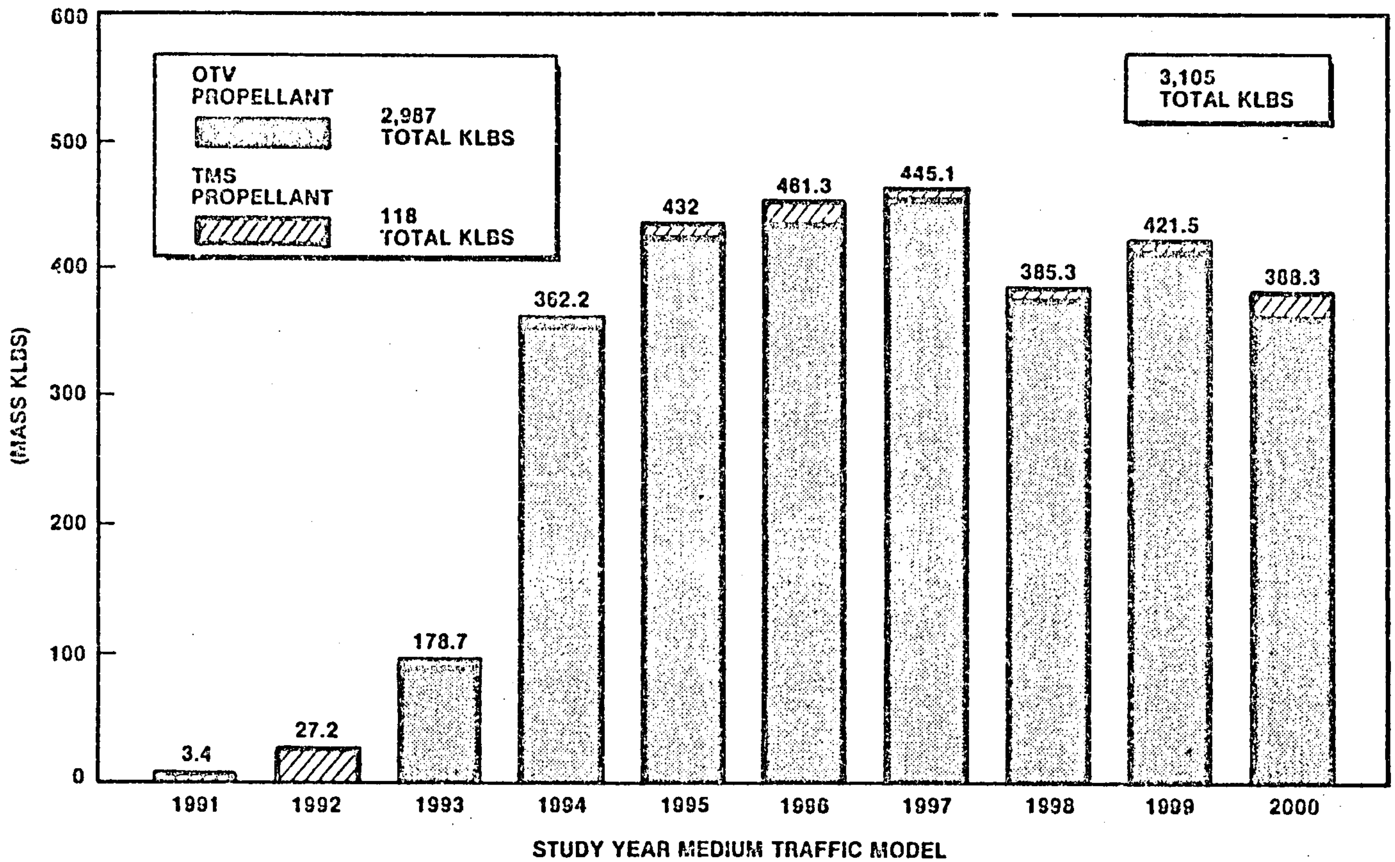
USER MISSION PROPELLANT REQUIREMENTS...



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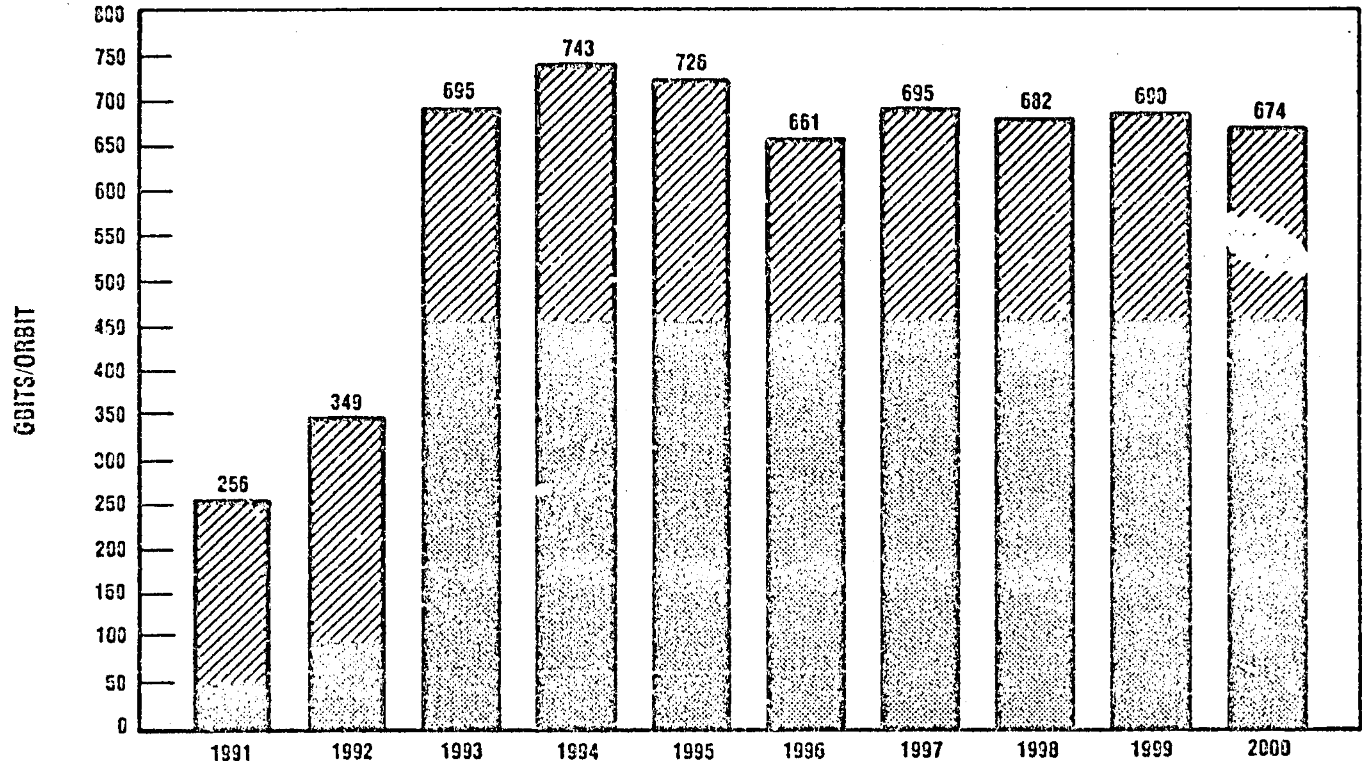
INTEGRATED DATA REQUIREMENTS . . .



STUDY YEAR
MEDIUM TRAFFIC MODEL

458 GBITS/ORBIT AVG 1993-2000 — STATION OPERATION REQUIREMENTS

265 GBITS/ORBIT/PEAK 1994 — PAYLOAD PROCESSING REQUIREMENTS

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SUMMARY BRIEFING OUTLINE ...

1. RECOMMENDED PROGRAM ARCHITECTURE
2. MISSIONS AND REQUIREMENTS
3. PROGRAMMATIC EVOLUTION
4. SPACE STATION ARCHITECTURE, TECHNOLOGY, AND COST
5. SPACE STATION ATTRIBUTES AND BENEFITS
6. CONCLUSIONS

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PROGRAMMATIC ISSUES

The most significant programmatic issues that were answered as a result of this study are:

- What is the best orbital location for the Space Station?
- What are the most effective Space Station services, and when should they and can they be introduced?

The following charts provide the key data that answers these issues.

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SPACE STATION

PROGRAMMATIC ISSUES ...

- WHAT IS THE BEST ORBITAL LOCATION FOR THE SPACE STATION?
- WHAT ARE THE MOST EFFECTIVE SPACE STATION SERVICES & WHEN SHOULD THEY & CAN THEY BE INTRODUCED?

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PROGRAM OPTIONS DEFINITION AND JUSTIFICATION

This chart defines the program options that were initially studied to determine the impact of total program and Space Station functions and location on Shuttle launches and program cost.

The first two options are single function Space Station options and are located at a 28-degree inclination and 200 nmi altitude. Option 1 conducts only high energy mission staging using a space-based reusable OTV. Shuttle scavenging is used to maximize propellant payload. The second option conducts only space processing mission support. High energy missions and other missions are conducted out of the Shuttle. The third option, also located at 28 degrees and 200 nmi provides support to all of the primary mission areas. This option also has space-based OTV's and TMS's. Shuttle propellant scavenging once again is used to maximize propellant mass to orbit. In Option 4, the Space Station is located at a 57-degree inclination and a 200 nmi altitude. This station supports space processing and a small number of Science and Applications missions that can be conducted in this region. The fifth option assumes no change in current and planned space support systems (no station). This option is used as a comparator to show how the Space Station options benefit compared with no station. A sixth option considered the use of two small stations located at 28-degree and 57-degree inclinations. The 28-degree station accomplished HEO staging (GEO and planetary) and supported local Science and Applications missions. The 57-degree station supported local Science and Applications and space processing missions and provided HEO staging of missions in the medium inclination region.

SPACE STATION

PROGRAM OPTIONS DEFINITION AND JUSTIFICATION ...

SPACE STATION				OTHER ELEMENTS			JUSTIFICATION
OPTION	FUNCTIONS	LOCA-TION	SIZE	OTV	TMS	SHUTTLE	
1	HIGH-ENERGY MISSION STAGING	28° 200 nmi	4-MAN	SPACE-BASED REUSABLE SINGLE-STAGE CRYOGENIC	GROUND-BASED & SPACE BASED REUSABLE BI-PROPELLANT	PROPELLANT SCAVENGING	DETERMINE FEASIBILITY SINGLE-PURPOSE SPACE STATION & COMPARE WITH OPTION 5
2	SPACE PROCESSING MISSION SUPPORT	28° 200 nmi	4-MAN	PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	SAME AS OPTION 1	STANDARD	DETERMINE FEASIBILITY OF SINGLE -PURPOSE SPACE STATION
3	MULTIPLE MISSION SUPPORT	28° 200 nmi	4-MAN 8-MAN	SAME AS OPTION 1	SAME AS OPTION 1	SAME AS OPTION 1	DETERMINE SYNERGISM OF COMBINED FUNCTIONS
4	SPACE PROCESSING & SCIENCE & APPLICATIONS MISSION SUPPORT	57° 200 nmi	4-MAN	SAME AS OPTION 2	SAME AS OPTION 1	SAME AS OPTION 2	DETERMINE IMPACT OF ORBITAL INCLINATION
5	NO SPACE STATION			PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	GROUND-BASED REUSEABLE BI-PROPELLANT	STANDARD	BASELINE PROGRAM FOR COMPARISONS
6	TWO SMALL MULTI-FUNCTIONAL STATIONS	28° 200 nmi 57° 200 nmi	4-MAN 4-MAN	SAME AS OPTION 1	SAME AS OPTION 1	PROPELLANT SCAVENGING	BALANCED MISSION SUPPORT AT TWO LOCATIONS

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COMPARISON OF PROGRAM OPTIONS

This chart compares the six program options. The data show the total number of Shuttle launches, total space support system cost (development, production, and operations), and a Shuttle launch summary for OTV options for program Option 3 (multimission support at 28 degrees inclination).

The launch summary shows that Option 3 leads to the lowest number of Shuttle launches. In addition, the cost comparison shows that Option 3 also leads to the lowest total support system cost through the year 2000.

The program cost and launch summaries assumed the use of a single-stage reusable OTV that is space-based at the station. The following upper-stage options are compared:

- Option 3 - Single-stage reusable OTV space-based at station
- Option 5 - No OTV and no Space Station
- Option 7 - Aerobraker reusable OTV space-based at station
- Option 8 - Perigee kick stage reusable OTV based at station

As shown, the PKS OTV results in the lowest number of Shuttle flights.

Because of the above comparison, a multifunctional Space Station located at 28 degrees inclination and 200 nmi altitude was selected for the conduct of more detailed subsequent studies. As will be shown, this Space Station benefits significantly all user areas in addition to being the most cost-effective overall. The perigee kick-stage OTV was selected to be space-based at this station. It is expected that the aerobraking OTV will eventually be developed for missions beyond the year 2000 where either large round-trip payloads (such as manned missions) to GEO may exist or where retrieval of payloads may be important.

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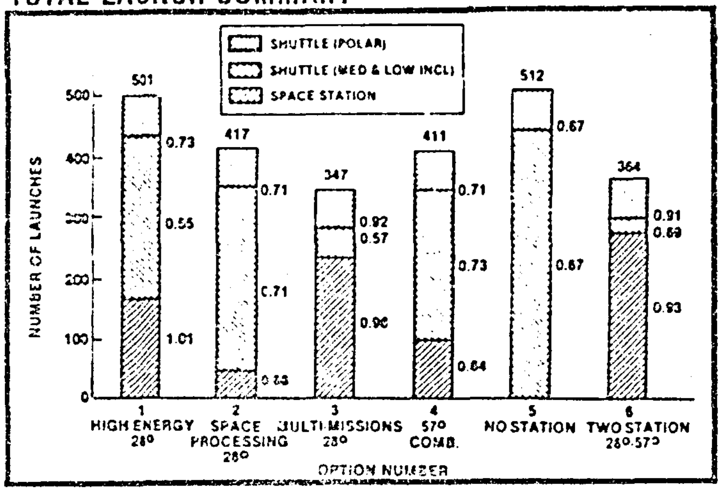
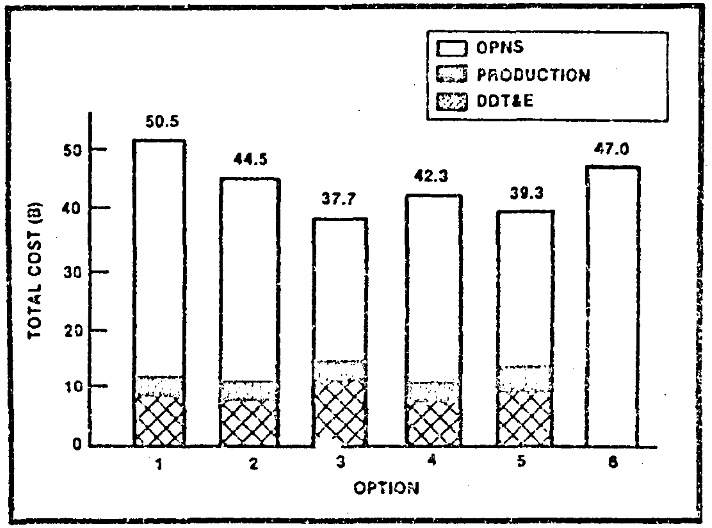
SPACE STATION

COMPARISON OF PROGRAM OPTIONS ...

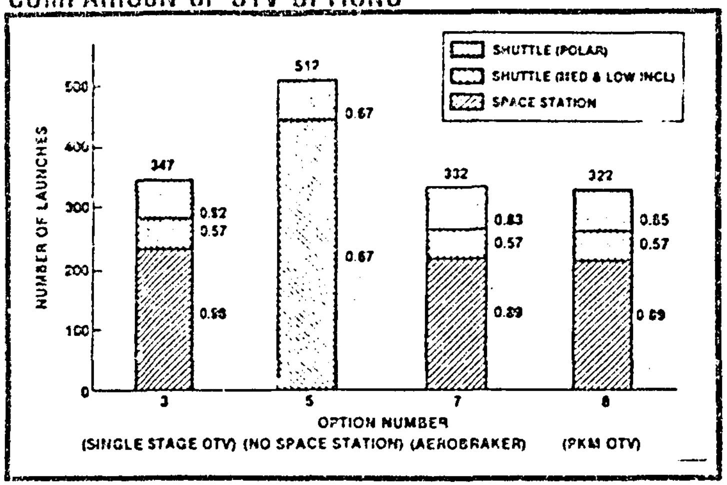
TOTAL LAUNCH SUMMARY



OPTIONS COST COMPARISON



COMPARISON OF OTV OPTIONS



CONCLUSION

- MULTIFUNCTIONAL STATION AT 28°
- REUSABLE LO_2/LH_2 PERIGEE KICK STAGE OTV SPACE-BASED AT STATION

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EVALUATION OF SPACE STATION SERVICES TIMING

Timing of Space Station services depends upon three major considerations: (1) when the user needs it, (2) when technology or demonstrations of the service is available, and (3) if it is a government-provided service, when budgetary considerations will allow it to happen. This chart provides an estimate of the date for initial operational capability of each Space Station service.

The user need is immediate with a station's initial operational capability (IOC) for low-orbit placement and retrieval, high-orbit placement, low-orbit servicing, attached and integral missions, and storage. Space Station IOC is 1991. For these services, technology development or demonstration is either unnecessary or can be accomplished out of the Shuttle prior to the Space Station IOC. If it is assumed that the TMS will be developed and used in Shuttle prior to the station IOC, budgetary considerations are not important for these services.

High orbit placement with the OTV space-based at the station is more challenging, because of the need to store and transfer cryogenic propellants on orbit and the cost of development of this capability and a new OTV. It is believed that most of the technology development and demonstration could be accomplished out of the Shuttle and that two years or less would be required at the station to provide an initial capability. In order to avoid an overlapping development of the Space Station and space-based OTV, it is estimated that a delay in OTV IOC to 1994-1995 may be necessary. For this study, the final manifesting analyses assumed a space-based OTV capability in 1994.

The user need for assembly and construction of mission payloads at the station will probably not occur until 4 or 5 years after demonstration of this capability at the Space Station by NASA. IOC dates for these capabilities would be 1995-1996 for assembly and 1999-2000 for construction. It does not appear, at this time, that budgetary considerations for these capabilities are important.

The only high energy orbit servicing that appears practical is in GEO, since a number of payloads exist in a single orbital plane and altitude. Users commitment to GEO servicing will probably be contingent upon successful early LEO servicing and OTV availability. Development costs will entail TMS modifications for a long-term stay at GEO with only resupply from the Space Station. An IOC of 1996 or 1997 is estimated for this capability.

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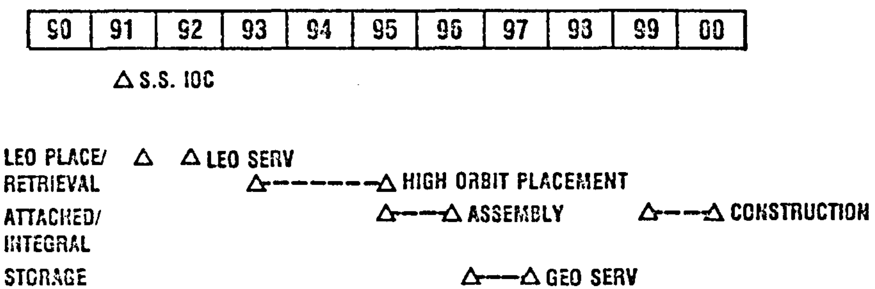
SPACE STATION

EVALUATION OF SPACE STATION SERVICES TIMING . . .

SERVICES	USER NEED	TECH/DEMO	BUDGETARY	IOC
LOW ORBIT PLACEMANT / RETRIEVAL	AT S.S.IOC	OUT OF SHUTTLE WITH TMS	BEFORE S.S. IOC (TMS)	1991
HIGH ORBIT PLACEMENT	AT S.S. IOC	SHUTTLE + S.S. (≈ 2 YRS)	COMMERCIAL? GOVERNMENT (1.1B)	1993-1995
LOW ORBIT SERVICING	AT S.S. IOC	OUT OF SHUTTLE + S.S. (≈ 1 YR)	SMALL $	1992
HIGH ORBIT SERVICING	4-5 YEARS AFTER COMMITMENT	EARLY LEO SERV + OTV AVAIL	TMS MODS (100M)	1996-1997
ATTACHED/INTEGRAL MISSIONS	AT S.S. IOC	NOT NECESSARY	AVAILABLE WITH BASIC S.S.	1991
ASSEMBLY	4-5 YRS AFTER COMMITMENT	1991	ASSEMBLY EQUIP (100M)	1995-1996
CONSTRUCTION	4-5 YRS AFTER COMMITMENT — WEAK REQUIREMENT	1995	CONSTRUCTION EQUIP (200M)	1998-2000
STORAGE	AT S.S. IOC	NOT NECESSARY	AVAILABLE WITH BASIC S.S.	1991



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COST IMPACTS OF GROWTH STATION AND OTV TIMING

This chart shows the effects of the growth station and OTV introduction year on peak annual funding and high energy user (commercial communications, DOD, and NASA Science and Applications) transportation costs.

The DDT&E and production costs of both the Space Station and OTV are included in the determination of annual funding. Introduction of the growth station and OTV in 1991 is equivalent to an all-up multi-functional eight-man station capability right away (no evolution from four-man to eight-man). As shown on the peak funding curve, peak funding drops from 2.5 billion for a 1991 introduction date to about 1.5 billion if the growth eight-man station and OTV are introduced in 1994. There is little advantage to peak funding by introducing the growth Space Station and OTV later than 1994, which is the year selected for the baseline program. In all cases, a four-man station is introduced in 1991 without the capability to conduct OTV operations.

However, the later the growth station and OTV are introduced, the greater the increase in transportation cost to the HEO user. This is caused by higher transportation costs of mass to LEO, and the increased use of expensive, expendable upper stages. The baseline year of 1994 results in a 21 percent increase (2.5 billion) in HEO user transportation costs compared to immediate all-up capability in 1991.

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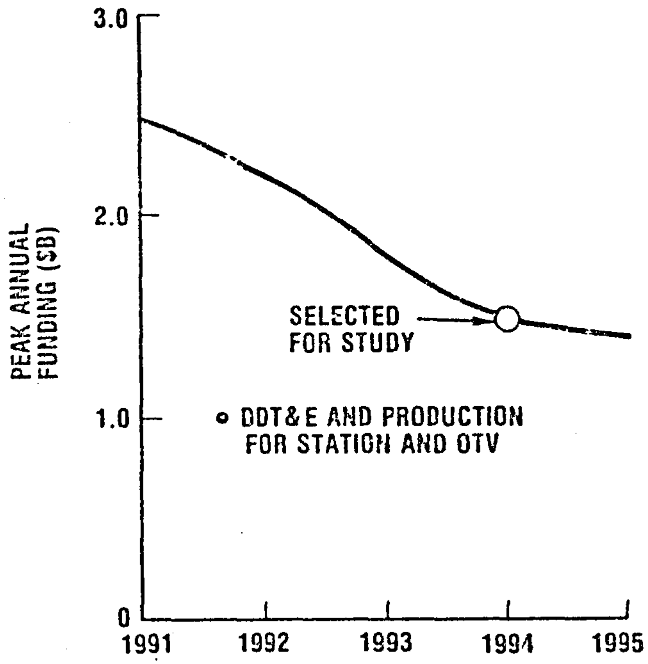
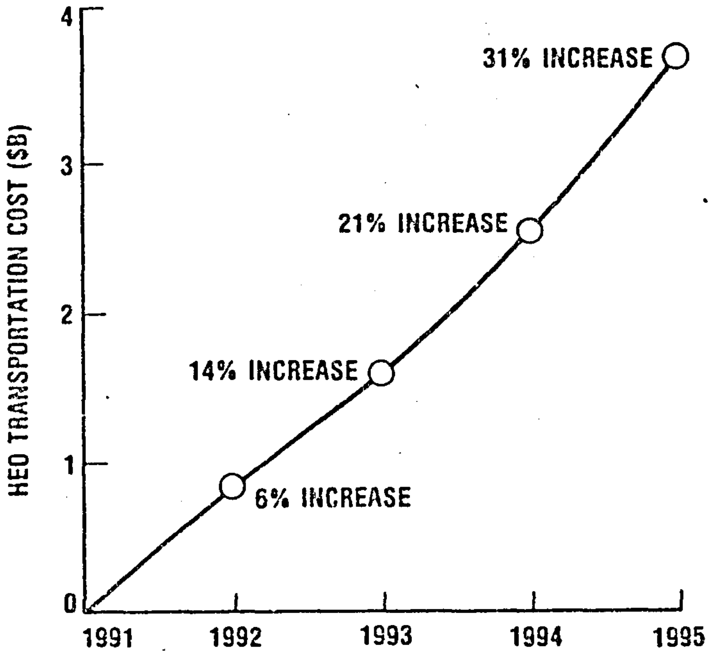
SPACE STATION

COST IMPACTS OF GROWTH STATION AND OTV TIMING ...

EFFECT ON PROGRAM PEAK ANNUAL FUNDING



EFFECT ON USER HEO TRANSPORTATION COST



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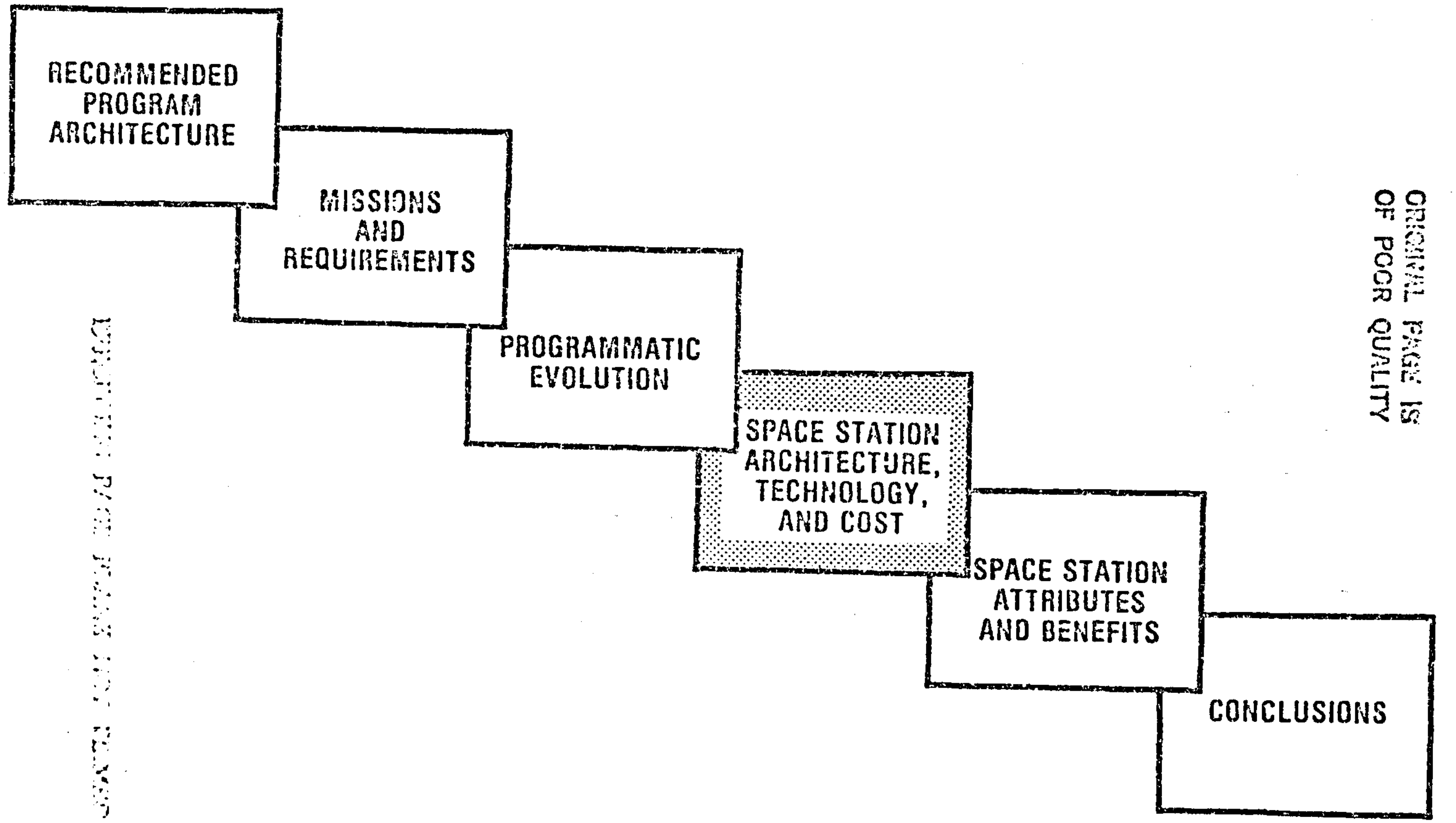
SUMMARY BRIEFING OUTLINE ...



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CONSTRAINTS ON SPACE STATION ARCHITECTURE

Four classes of constraints that significantly influence the station architecture are identified in this chart.

1. The presence of man in space is a significant driver. In addition to providing a comfortable and habitable atmosphere for the crew members, their safety introduces a number of issues such as the dual volumes, redundant subsystems, and space environment protection. Repair and maintenance activities required the crew member to perform these tasks in the space environment, thus requiring EVA facilities and the design of equipment to be compatible with this form of activity. Design conditions are also placed on the equipment and space allocations within the modules, which will permit a crew member to perform emergency repairs in an unpressurized module.

2. Subsytem design issues that are drivers of the architecture include the location and aspect ratio of the solar arrays to minimize the shadowing effects on the arrays from the station elements. Attitude control of the station must consider the extreme changes in station center-of-gravity locations because of the various activities occurring on the station such as OTV/payload assembly and launch and orbiter mating. Proper heat rejection requires available surface areas with clear radiation views.

3. The Shuttle's cargo bay dimensions and lifting capabilities constrain module sizes. The station configuration is significantly influenced by the orbiters large vertical surface and the required cargo unloading clearances.

4. Provisions to accept dedicated experiment modules identified by the mission model imposes constraints not only on the provisions for mating ports but also on the interior arrangement that must provide access to these ports for the pressurized experiment modules.

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SPACE STATION

CONSTRAINTS ON SPACE STATION ARCHITECTURE ...

MAN IN SPACE

- CREW SAFETY — DUAL VOLUMES, REDUNDANT SUBSYSTEMS
- EVA ACCOMMODATIONS
- CREW HABITABILITY VOLUME
- SPACE ENVIRONMENT PROTECTION
- SHIRTSLEEVE & IVA MAINTENANCE

SYSTEMS

- SOLAR ARRAY DRAG, SHADOWING
- ATTITUDE CONTROL — C.G. TRAVEL
- HEAT REJECTION

SHUTTLE

- SHUTTLE CAPABILITY
- ORBITER CLEARANCE — FOR UNLOADING & VERTICAL TAIL CLEARANCE

MISSION PAYLOADS

- AVAILABLE PORTS FOR EXPERIMENT MODULES

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ALTERNATE SPACE STATION ARCHITECTURE OPTIONS

Two growth Space Station architecture options for implementing the mission model are illustrated on this chart. The two options consider a multidiscipline station that accommodates all of the missions and service activities on one Space Station while the other concept considers two small stations.

The multidiscipline station provides the capabilities to perform various functions simultaneously, such as satellite assembly, OTV launch and retrieval, remote servicing of satellites via TMS, life sciences experiments, earth observations, astronomy observations, and space processing research and production. The compatibility of these many functions, particularly in the growth configuration, may not be acceptable, or at best constraining to the scheduling of the operations of the various activities.

The various functions identified in the mission model are separated into more compatible groups in the two-station concept. Space Station 1 accommodates the science, technology, and space processing activities, while Space Station 2 accommodates the space operations activities associated with OTV's and TMS's. Each of the stations has the capability to grow to accommodate more than a crew of four. The two-station concept utilizes the same energy module and command module elements. The payload support assemblies are designed for the most effective use required by the particular disciplines of each station.

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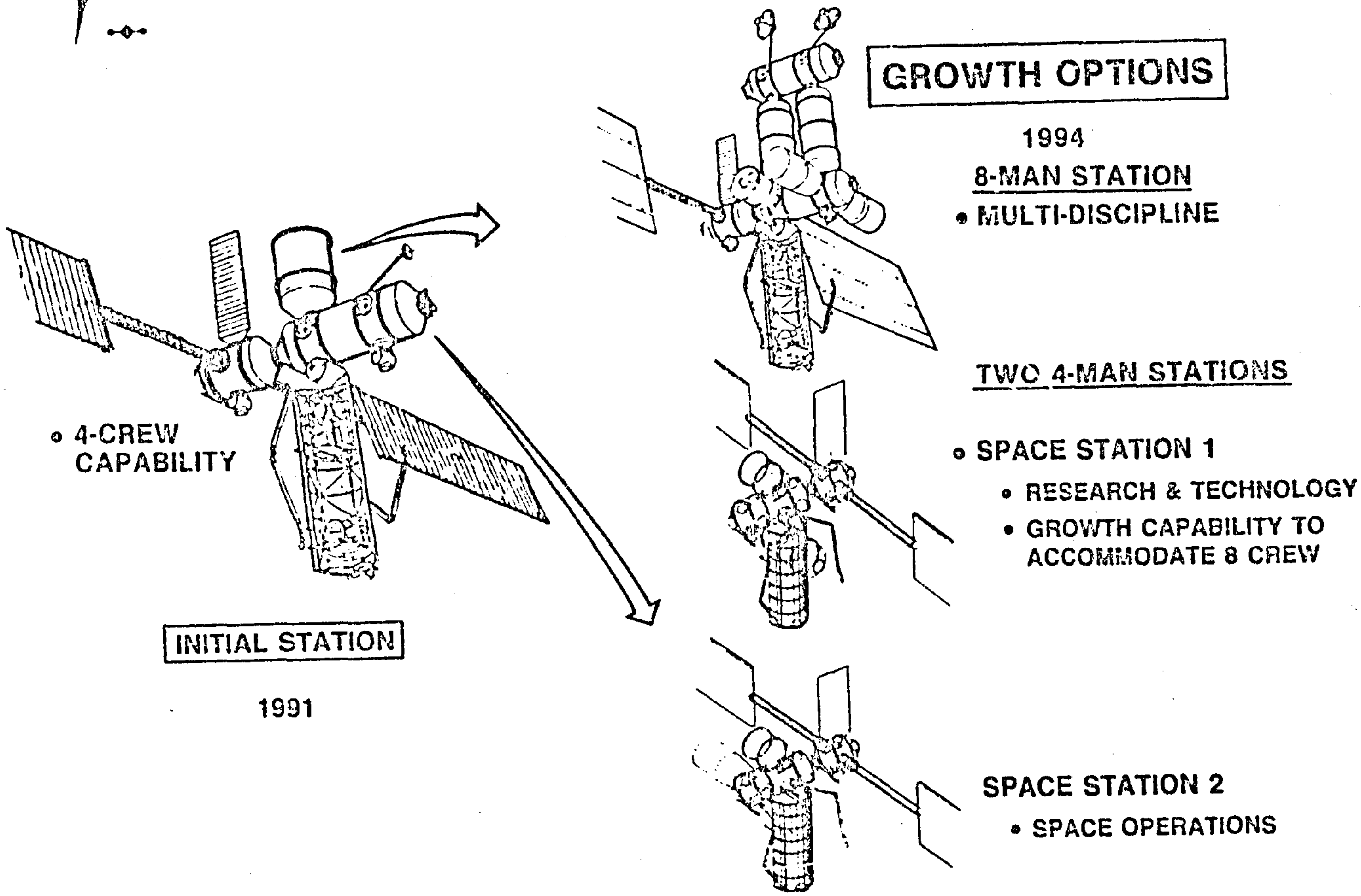
SPACE STATION

ALTERNATE SPACE STATION ARCHITECTURE OPTIONS . . .



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INITIAL SPACE STATION ARCHITECTURE

The initial station illustrated on this chart represents the configuration that would apply for either station architecture concept described on the previous chart. The functions that would be provided and the significant characteristics are indicated.

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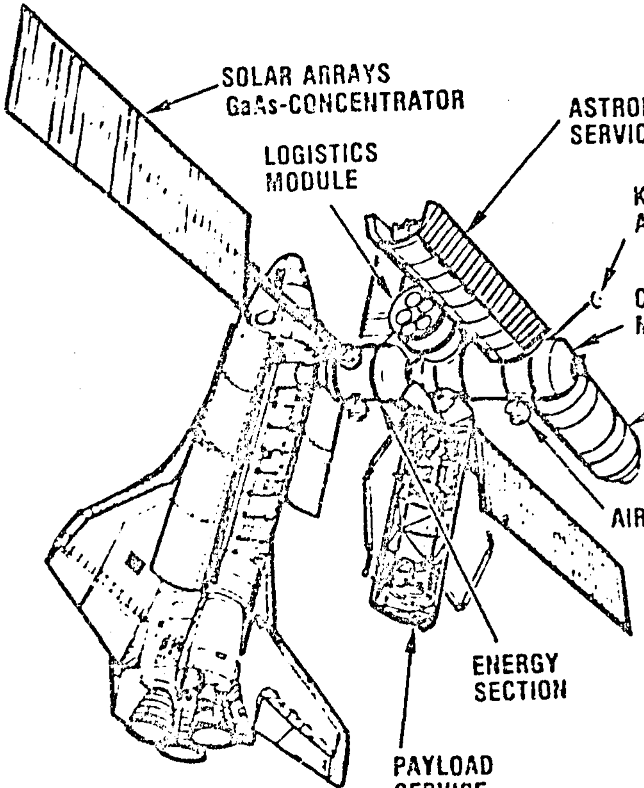
INITIAL SPACE STATION ARCHITECTURE...



FUNCTION:

- ACCOMMODATE SPACE OPERATIONS
  - LEO SERVICING OF SATELLITES
  - SCIENCE EXPERIMENT MODULES / PALLETS
  - R&D
  - SPACE PROCESSING
- PROVIDE ELECT. POWER, COMMUNICATIONS, CREW ACCOMMODATIONS

CHARACTERISTICS:

- 4 MATING PORTS TO ACCEPT EXPT MODULES
- PALLET MOUNTING ACCOMMODATIONS ON PSA
- 23.5 kW POWER AT BUS
- ACCOMMODATIONS FOR 4 CREW
- REPLACEABLE SOLAR ARRAYS & RADIATOR
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

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GROWTH EIGHT-MAN SPACE STATION ARCHITECTURE

This station configuration represents the growth station that would provide all of the capabilities required to implement the mission model, spacecraft services, science experiments, and crew accommodations. The significant characteristics are also indicated.

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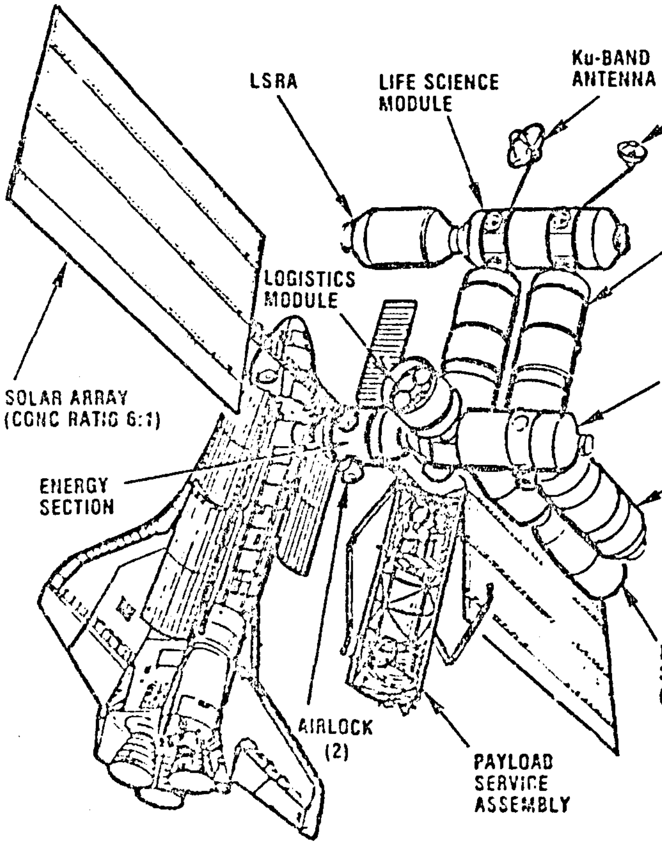
SPACE STATION

GROWTH 8-MAN SPACE STATION ARCHITECTURE ...



FUNCTIONS:

- ACCOMMODATE SPACE OPERATIONS
  - SCIENCE EXPERIMENT MODULES/PALLETS & INTERNAL VOLUME
  - SERVICE OTV'S, TMS & SPACECRAFT
  - R&D
  - SPACE CONSTRUCTION & ASSEMBLY
  - SPACE PROCESSING RESEARCH & FACTORY
- PROVIDE ELECT. POWER, COMMUNICATIONS, CREW ACCOMMODATIONS

CHARACTERISTICS:

- 8 MATING PORTS TO ACCEPT EXPT MODULES
- PALLET MATING ACCOMMODATIONS ON PSA
- OTV/SPACECRAFT SERVICING ACCOMMODATIONS ON PSA
- CRYO STORAGE
- 50 kW POWER AT BUS
- ACCOMMODATIONS FOR 8 CREW
- REPLACEABLE SOLAR ARRAYS & RADIATOR
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

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GROWTH FOUR-MAN STATION ARCHITECTURE, FUNCTIONS, AND CHARACTERISTICS

The following two charts illustrate the two four-man Space Station concept and its functions and characteristics. The principal accommodation differences are in the payload service assembly configurations and in the cryo propellant storage facilities. The science and technology station has a payload service assembly that is configured to accommodate up to eight Shuttle pallet-mounted earth and astronomy observation sensors. The payload service assembly of the Space Operations Station is configured to temporary storage of satellites, which will be delivered to higher orbits via an OTV. Facilities to service two OTV's are also provided as is the servicing of two TMS spacecrafts.

The cryo storage tanks on the Space Operations Station provides the propellant for the OTV spacecraft. Storable propellant storage also is provided on the PSA for the servicing of the TMS.

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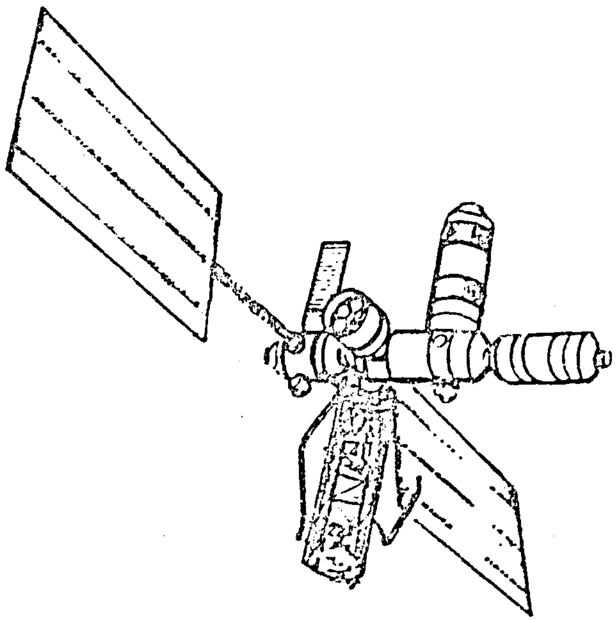
GROWTH 4-MAN STATIONS ARCHITECTURE...

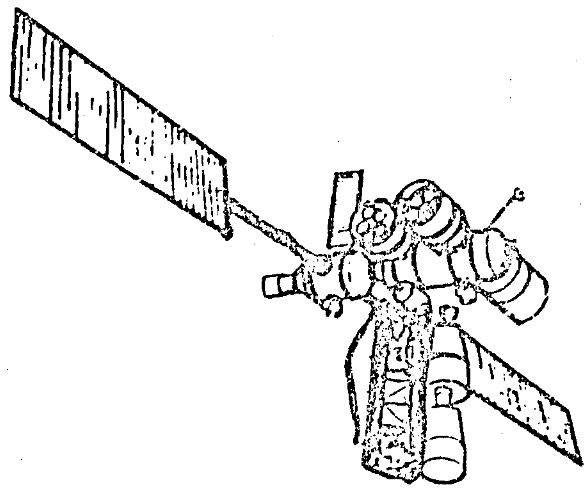
STATION 1

RESEARCH & TECHNOLOGY
SPACE STATION



STATION 2

SPACE OPERATIONS
SPACE STATION



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SPACE STATION

GROWTH 4 MAN STATION FUNCTIONS & CHARACTERISTICS ...

STATION 1
SCIENCE & APPLICATIONS

FUNCTIONS:

- ACCOMMODATE SCIENCE & APPLICATIONS & SPACE PROCESSING RESEARCH & TECHNOLOGY
  - MODULES, PALLETS, INTERNAL
- PROVIDE ELECT. PWR, COMMUNICATIONS, CREW ACCOMMODATIONS FOR 4

CHARACTERISTICS:

- PALLET MOUNTING ACCOMMODATIONS ON PSA
- ELECT PWR GROWTH CAPABILITY
- ACCOMMODATES 4 CREW WITH GROWTH TO 8
- DUAL VOLUMES FOR CREW SAFETY
- EVA ACCOMMODATIONS

STATION 2
GEO STAGING

FUNCTIONS:

- ACCOMMODATE GEO & TMS STAGING MISSIONS
- PROVIDE REUSABLE OTV & TMS SERVICING
- PROVIDE PAYLOAD ASSEMBLY & SYSTEM VERIFICATION
- PROVIDE ELECT. PWR, COMMUNICATIONS, CREW ACCOMMODATIONS FOR 4
- ACCOMMODATE R&D IF NECESSARY

CHARACTERISTICS:

- CAPABILITY TO ACCOMMODATE MULTIPLE OTV'S & TMS
- CRYO & STORABLE PROPELLANT STORAGE
- PAYLOAD ASSEMBLY & VERIFICATION CAPABILITY
- ELECTRICAL POWER GROWTH CAPABILITY
- ACCOMMODATES 4 CREW WITH GROWTH TO 8
- DUAL VOL FOR CREW SAFETY
- EVA ACCOMMODATIONS

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SYSTEM Z PLATFORM

System Z represents a grouping of earth observation sensors that operate in polar orbit. This figure illustrates a platform concept accommodating these earth observation sensors. This platform concept utilizes two Space Station derived elements: the platform structure and the energy module. The platform structure is similar to the station payload service assembly. This structure simulates the orbiter payload bay and, therefore, can accept the standard Shuttle pallets and their attachments. The energy module of the platform is similar to the station energy module. The solar array and radiator plug-in concept of the station's energy module permits the flexibility of modifying the energy module to the system Z platform requirements. The standard mating ports on the platform structure and on the free end of the energy module permit the Shuttle orbiter to mate with the platform for servicing and for the changeout of sensor pallets or individual instruments.

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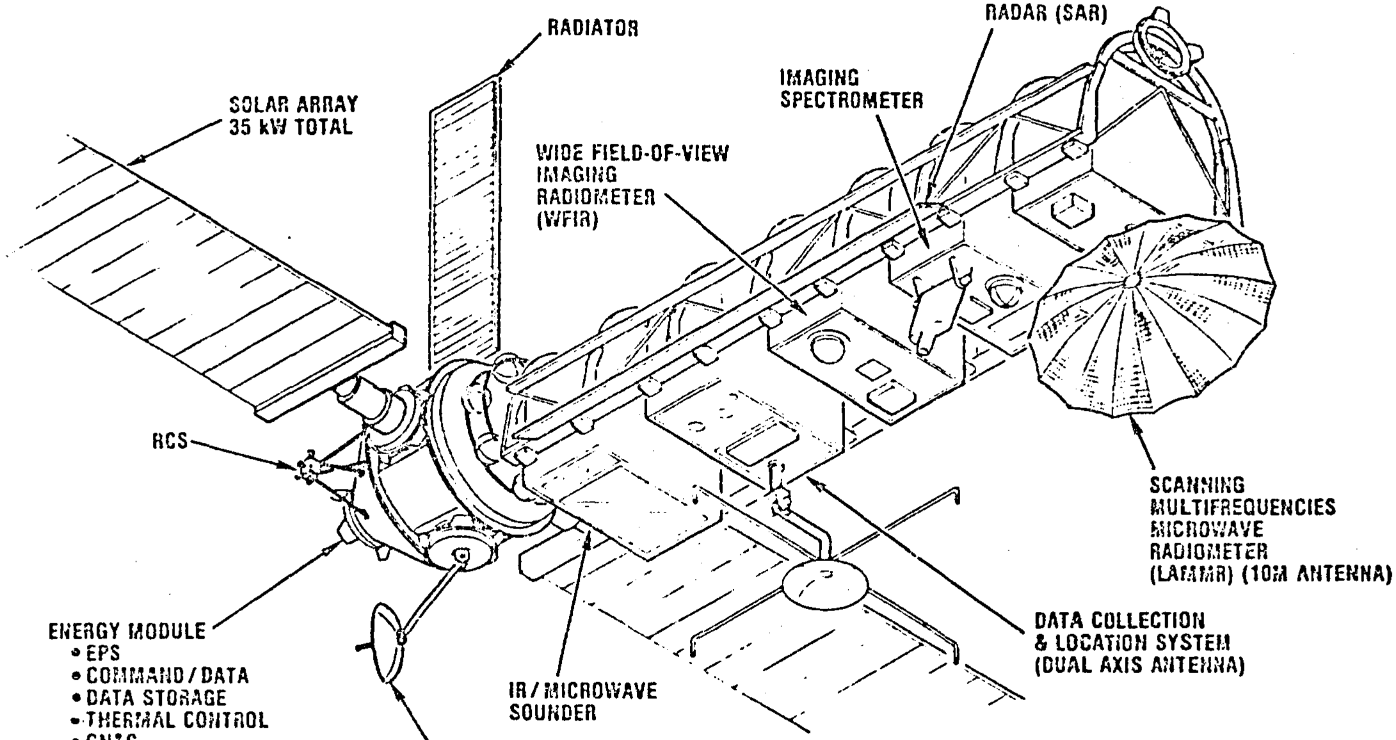
SYSTEM Z PLATFORM...



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SPACE STATION SUBSYSTEM ORGANIZATION

This chart shows the elements that are included in each of the major subsystem areas.

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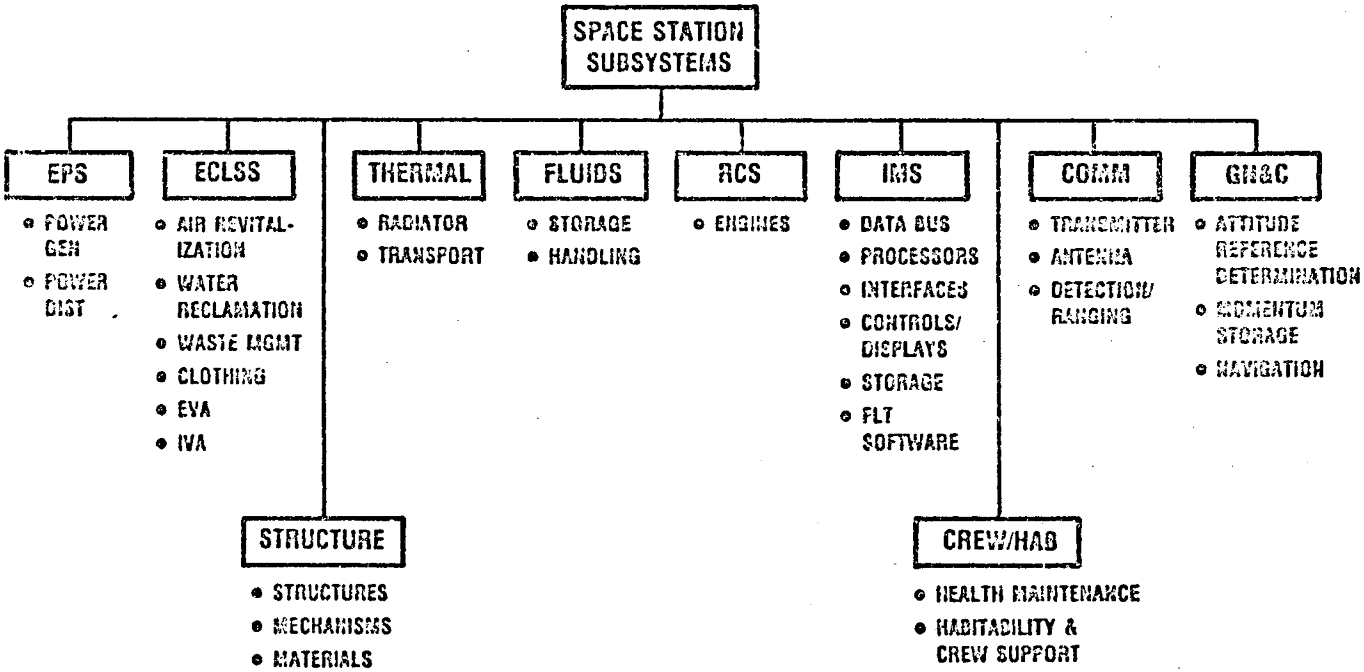
SPACE STATION

SPACE STATION SUBSYSTEM ORGANIZATION . . .



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SUBSYSTEM TECHNOLOGY CANDIDATES

In the electrical power subsystem (EPS), regenerative fuel cells are the Rockwell-preferred technology for power storage and generation during occultation. Evaluation studies have shown them to be superior to batteries and/or open-cycle fuel cells in terms of weight and system flexibility. 416 Vac was selected for distribution over the various dc voltage levels because of higher efficiency and lower system weight.

In the environmental control and life support subsystem (ECLSS) area, solid amine for CO_2 removal and the Sabatier process for CO_2 reduction were judged preferable to an electrochemical deployed cell and the Bosch process because of inherent system simplicity. Water electrolysis for oxygen supply was found to be more cost effective than logistical methods.

For water reclamation, the thermoelectric integrated membrane evaporation subsystem (TIMES) was selected over vapor compression distillation for reasons of simplicity and applicability to a wider variety of waste water. The incinerator approach for waste management is preferred over the orbiter commode because of substantial savings in logistics and handling costs. Similarly, reusable apparel (with a washer/dryer) was found to be more cost effective than disposable clothing.

In the thermal control subsystem, a wraparound heat pipe radiator was devised to handle anticipated thermal loads and eliminate the need for a deployable radiator. This was made possible largely by use of a capillary-pumped, two-phase fluid, heat transport loop that eliminated the heat load of a mechanical pump and provided the higher coefficients of boiling and condensing heat transfer.

Inasmuch as LO_2/LH_2 will be supplied anyway for OTV usage, GO_2/GH_2 RCS engines were selected over hydrazine because of substantial gains in I_{sp}.

In the inventory management subsystem (IMS), fiber optics is recommended for the data bus (rather than hardwire) because of its much higher data rate capacity. Instead of a centralized process hierarchy, a distributed configuration was chosen because of inherent advantages in fault detection and compensation. A bus interface unit (BIU) mode is recommended over the conventional multiplexer/demultiplexer (MDM) hookup because of superior capabilities in controlling and interfacing with the various subsystem levels.

For space communication, radio frequency (RF) was chosen over laser on the basis of development risk, cost, and tolerance of atmospheric disturbances. The RF antennas are of three main types: dedicated utilization for discrete frequencies, dispersed location for multidirection capability, and tracking/pointing for high gain, high rate data links. Radar is favored for detection and ranging functions, although use of the Navstar global positioning system (GPS) is still a strong contender for certain satellites that could be cost-effectively outfitted with GPS relay equipment.

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SUBSYSTEM TECHNOLOGY CANDIDATES . . .

SUBSYSTEM	TECHNOLOGY CANDIDATES
EPS	
• POWER GENERATION	• SOLAR ARRAY — BATTERY
	— [REGENERATIVE FUEL CELL]
	— FUEL CELLS (FC)
	— BATTERIES + FC
• DISTRIBUTION	• 28 VDC, 120 VDC, 220 VDC
	[• 416 VAC]
ECLSS	
• AIR REVITALIZATION	• CO_2 REMOVAL — [SOLID AMINE]
	— ELECTROCHEMICAL DEPLOYED CELL
	• CO_2 REDUCTION — [SABATIER]
	— BOSCH
	• O_2 SUPPLY — [WATER ELECTROLYSIS]
	— LOGISTIC SUPPLY
• WATER RECLAMATION	• VAPOR COMPRESSION DISTILLATION
	[• TIMES]
• WASTE MANAGEMENT	• ORBITER COMMODE
	[• INCINERATOR]
• CLOTHING	• DISPOSABLE
	[• REUSABLE]
THERMAL	
• RADIATOR	[• WRAPAROUND — HEAT PIPE]
	• DEPLOYABLE — HEAT PIPE
• TRANSPORT	• CIRCULATING PUMPS (SINGLE PHASE)
	[• CAPILLARY PUMP (TWO PHASE)]

[ ] = ROCKWELL PREFERRED CANDIDATE

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SPACE STATION

SUBSYSTEM TECHNOLOGY CANDIDATES (CONT) . . .

SUBSYSTEM	TECHNOLOGY CANDIDATES
RCS	
• ENGINES	• HYDRAZINE • **LO_2/LH_2 — GASEOUS**
IMS	
• DATA BUS	• **HARDWIRE** • **FIBER OPTICS**
• PROCESS HIERARCHY	• CENTRAL • **DISTRIBUTED**
• INTERFACES	• MDM • **BIU**
COMMUNICATIONS	
• COMMUNICATION TYPE	• **RF** • LASER
• ANTENNAS	• DEDICATED UTIL • DISPERSED LOCATION • TRACKING/POINTING
• DETECTION/RANGING	• **RADAR**
GN&C	
• ATT REF DETERMINATION	• STAR SENSING • INERTIAL SENSING
• MOMENTUM STORAGE	• CENTRALIZED ACTUATORS • **DISTRIBUTED**
• NAVIGATION	• **GPS**

[ ] = ROCKWELL PREFERRED CANDIDATE

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EVALUATION OF TECHNOLOGY IMPROVEMENTS (HIGH LEVERAGE ITEMS)

A capillary-pumped, two-phase fluid, heat transport loop represents a major advance over conventional transport loops in terms of simplicity, weight, reliability, performance, and lack of parasitic heat loads that, in the case of Space Station, permits use of a wraparound radiator rather than a deployed radiator. A large reduction in radiator size is also achievable by developing long-life thermal coatings. For instance, a change in the annual rate of degradation from 0.02 to 0.01 permits a 50 percent savings in radiator size.

In the EPS, low-concentration ratio (6:1), GaAs solar arrays promise a 4:1 reduction in recurring costs for large (100 kW) u.'ts, when compared to conventional planar silicon arrays. The higher efficiency of GaAs cells also reduces collector area and drag. Substantial reductions (2:1) in energy storage weight and improved system flexibility are offered by use of regenerative fuel cells or NiH_2 batteries (versus NiCd atteries). Drastic improvements (10:2 to 20:1) in fuel cell life and replacement costs are believed possible with intensive development. In the distribution system, weight and efficiency gains are obtainable in the 50 kW range by going to higher bus voltages such as 220 Vdc or 416 Vac. AC has the advantage of greater flexibility in power processing and interfacing with special loads. This system can benefit from potential new improvements in inverter efficiency to 90 percent to 93 percent (versus 75 percent to 80 percent, conventional).

In the ECLSS, substantial savings ($45M to $60M) in logistics and handling costs can be realized by processing and disposal of trash and fecal waste in an on-station incinerator. Similarly, a washer/dryer on-station can save $60M to $80M in program costs, compared to the use of disposable clothing.

In the IMS, potential advances of 8:1 in data compression (with acceptable error rates) are considered possible. Also, very high speed integrated circuits (VHSIC) for computers and microprocessors promise great improvement in avionics compactness, redundancy, and fault detection/ compensation. The use of fiber optics for data bus (versus hardwire) can achieve data rates deep into the megabit range. Bus interface units (BIU's) with VHSIC chips can provide "smart" interface monitoring and control down to the lowest unit level.

For data communication, the advance' telemetered data acquisition subsystem (TDAS) promises continuous rates of 300 megabits per second (or 60 mps for a 20-minute transmission averaged over a 92-minute orbit).

In the guidance, navigation, and control (GN&C) area, automated docking will be required for unmanned operations, but it also offers attractive savings in crew time and higher reliability and safety for manned stations. Distributed processing of GN&C functions versus centralized control offers worthwhile advantages in overall cost and reliability. Larger size control moment gyro (CMG) designs can provide lower weight and cost and a simpler overall subsystem.

The use of gaseous O_2/H_2 for RCS thrusters (instead of conventional hydrazine) integrates well with cryopropellant resupply for OTV's and offers worthwhile savings in transport costs, because of higher I_{sp} (380 seconds versus 200 seconds).

Processing of OTV propellants on orbit provides a means of circumventing the launch hazard problem, which has always been an obstacle to the use of high performance LF_2/LH_2 engines rather than LO_2/LH_2 engines.

The higher mixture ratio of fluorine engines also reduces the required volume of LH_2 by approximately one half and improves the OTV mass fraction. For very high ΔV missions (MOTV, DOD, and planetary), the payload improvement can be large.

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SPACE STATION

EVALUATION OF TECHNOLOGY IMPROVEMENTS (HIGH LEVERAGE ITEMS) . . .

SUBSYSTEM	CURRENT TECHNOLOGY	POTENTIAL ADVANCES	PERFORMANCE/ COST IMPACT
THERMAL CONTROL			
• THERMAL BUS	CIRCULATING PUMP — SINGLE-PHASED FLUID SYST	CAPILLARY PUMP — TWO-PHASE FLUID SYSTEM	• MINIMIZE (OR ELIMINATE) DEPLOYED RADIATOR • 5 kWe PUMP POWER SAVINGS
• THERMAL COATINGS	$\alpha = 0.1 + 0.02 \times$ LIFE	$\alpha = 0.1 + 0.01 \times$ LIFE	• LONGER LIFE SYSTEM • 50% RADIATOR AREA SAVINGS
EPS			
• POWER GENERATION	PLANAR SILICON SOLAR ARRAYS	LOW CONCENTRATION GaAs SOLAR ARRAYS ~ 100 kW	• ONE-FOURTH RECURRING COST (CONC RATIO, 6:1) • GaAs SAVES 1/2 NO. OF CELLS
• ENERGY STORAGE	NiCd BATTERIES	REGEN. FUEL CELLS NiH_2 BATTERY	• ONE-HALF (LOWER) WEIGHT • POWER FLEXIBILITY • SIMPLER INTEGRATION
• FUEL CELLS	10,000 kWh LIFE	10,0000-200,000 kWh LIFE	• LOWER REPLACEMENT COSTS
• POWER DISTRIBUTION	28 VDC	HIGH VOLTAGE • 120 VDC • 220 VDC — 50 kWe • 416 VAC	• LIGHTER DISTR WEIGHTS • HIGHER DISTR EFFICIENCY
• INVERTER	75-80% EFFICIENCY	90-93% EFFICIENCY	• LOWER ARRAY AREA
ECLSS			
• WASTE MANAGEMENT	FECAL BAG COLLECTION	INTEGRAL WASTE & TRASH DISPOSAL (INCINERATOR)	• ELIMINATE 334 CHANGEOUTS — 20 YEARS • $45M-$60M SAVINGS
• CLOTHING	DISPOSABLE	REUSABLE — WASHER/DRYER	• 83,000 LB SAVINGS • $50M-20M LESS COST

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SPACE STATION

EVALUATION OF TECHNOLOGY IMPROVEMENTS (CONT) (HIGH LEVERAGE ITEMS) . . .

SUBSYSTEM	CURRENT TECHNOLOGY	POTENTIAL ADVANCES	PERFORMANCE/ COST IMPACT
IMS			
• DATA COMPRESSION	2:1; 4:1 (TOLERATE ERRORS)	8:1 (WITH ACCEPTABLE ERROR RATES)	• INCREASED DATA RATE CAPABILITY - - GIGA BITS
• COMPUTER PROCESSING HARDWARE — PROCESSING DESIGN & SIGNAL CONDITIONING	LSI	VHSIC	• POWER SAVINGS, SMALLER SIZE ENHANCES REDUNDANCY & FAULT TOLERANCE
• DATA BUS STRUCTURE	WIRE	FIBER OPTICS	• HIGHER DATA RATE CAPACITY >> MBPS
• INTERFACE UNITS	MDM	DIU (WITH VHSIC CHIPS)	• STANDARDIZATION USING "SMART" INTERFACE UNIT — ALLOWS CONTROL DOWN TO LOWEST POSSIBLE LEVEL
COMMUNICATION			
• DATA RELAY	TDRSS	ADVANCED TDRSS	• PERMITS HIGHER TRANSMISSION RATES > 60 MPS (EQUIV)
GN&C			
• DOCKING	MANUAL	AUTOMATIC	• REQUIRED FOR UNMANNED OPS • CREW TIME SAVINGS • HIGHER RELIABILITY & SAFETY
• PROCESSING	CENTRAL	DISTRIBUTED	• LOWER COST, HIGHER RELIABILITY
• CMG	SKYLAB	LARGER SIZE, LOWER WEIGHT	• LOWER LAUNCH COST; SIMPLER SYSTEM
RCS/FLUIDS			
• THRUSTERS	HYDRAZINE	GOX/GH_2	• HIGHER SPECIFIC IMPULSE — 380 SEC
• OTV FUEL FORM (OTV HIGH ENERGY PROPELLANTS)	LOX/LH_2 (GROUND CONVERSION)	LF_2/LH_2 ($NF_3 + LH_2 \rightarrow N_2H_4 + LF_2$) (ON ORBIT CONVERSION)	• LAUNCH SAFETY • HIGHER SP IMPULSE — 490 SEC

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COST COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS

This chart shows the design, development, test, and evaluation (DDT&E), production and operations and support costs for the initial four-man station (operational from 1991 to 1993) and two architectural options for the growth station (operational from 1994 to 2000). As shown, the total cost for the initial station is 5.43 billion. If growth is from a four-man station to an eight-man station, the growth station total cost is 4.17 billion. This is about the same as the 4.26 billion total cost of a growth concept that uses the two four-man station previously described. Very little DDT&E is required when growing to the two four-man stations; however, the production cost is higher for the two 4-man station scheme because of the need to completely replicate the four-man station. Operations and support costs are higher primarily because of the need to supply two stations (two logistics modules versus one), which is less efficient than logistics to a single station.

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SPACE STATION

COST COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS...

	INITIAL STATION 1991-1993	4-TO 8-MAN SS 1994-2000	4-TO 2 4-MAN SS 1994-2000
DDT&E	3930	1200	170
PRODUCTION	700	470	720
O & S	800	2500	3370
TOTAL	5430	4170	4260

IN MILLIONS OF 1984 $

INCLUDES COSTS FOR SPACE STATION CONTRACTOR HARDWARE, SPACE STATION ASSEMBLY AND LOGISTICS FLIGHT COSTS, SPACE STATION OPERATIONS AND SUPPORT COSTS, AND CONTRACTOR WRAP AROUNDS

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COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS

This chart shows additional comparative data for the two growth options.

The cost data on the previous chart has been arranged to determine the total ten-year costs for the two architectural options. The differential in cost during this period is trivial.

More manhours are available for services from the eight-man growth station options since nearly the same amount of crew time (about one man per station) is required for station management whether it is a four-man or eight-man station.

Growth capability is better for the two four-man station option than for the eight-man station option because both of the stations can readily grow to an eight-man capability. Usable volume for the eight-man option is nearly twice that of the two four-man option. Addition of the two crew modules and the tunnel module for the eight-man station results in a large additional volume. The tunnel module's excess volume is used for a life sciences laboratory. The two four-man station option would require an additional attached dedicated module for this purpose.

There is no difference in available ports for attached payloads between the two options.

Safety during the initial four-man station period is the same for both options (21-day wait for a rescue orbiter). The two four-man option has an advantage in that the second nearby station can provide a haven in an emergency. This would require a means of transporting the crew from one station to another. A possibility would be to use the TMS to transport men in a removable airlock between the two stations.

The major advantage, and the most important reason for considering the two four-man station option, is the separation of potentially conflicting functions. R&D and space processing missions usually want low-g and inertial Space Station pointing. When the OTV operations and increased TMS operations are introduced in 1994, a large increase in station disturbance level will exist and the need to orient the station for increased Shuttle, OTV, and TMS docking will interrupt other specialized orientation requirements. For these reasons, it may be desirable to have two stations with nonconflicting requirements.

Considerable additional study is needed to determine which of these approaches is most desirable.

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SPACE STATION

COMPARISON OF SPACE STATION ARCHITECTURE OPTIONS...

	4 MAN → 8 MAN		4 MAN → 24 MAN	
STATION COST				
• DDT & E	5,130		4,100	
• PRODUCTION	1,170		1,420	
• OPERATIONS (10 YRS)	3,300		4,170	
• TOTAL	9,600		9,690	
MISSION MAN-HOURS AVAILABLE/YR FOR SERVICES	21,840		18,720	
GROWTH CAPABILITY	PROBABLY NEED TO ADD ANOTHER STATION FOR GROWTH > 10 MAN		CAN GROW BOTH 4-MAN TO 8-MAN	
USABLE VOLUME (FT3)	3,840	13,700	3,840	7,680
NO. OF PORTS AVAILABLE	4	8	4	8
SAFETY	SHUTTLE RESCUE ONLY MODE — — 21 DAYS WAIT		• SAME FOR INITIAL • TWO STATIONS PROVIDE MUTUAL HAVEN IN EMERGENCY	
OPERATIONAL COMPATABILITY	LOW-G REQUIREMENT CONFLICTS WITH OTV & SERVICING FUNCTIONS		CAN SEPARATE CONFLICTING FUNCTIONS — R & D STATION — OPERATIONAL STATION	

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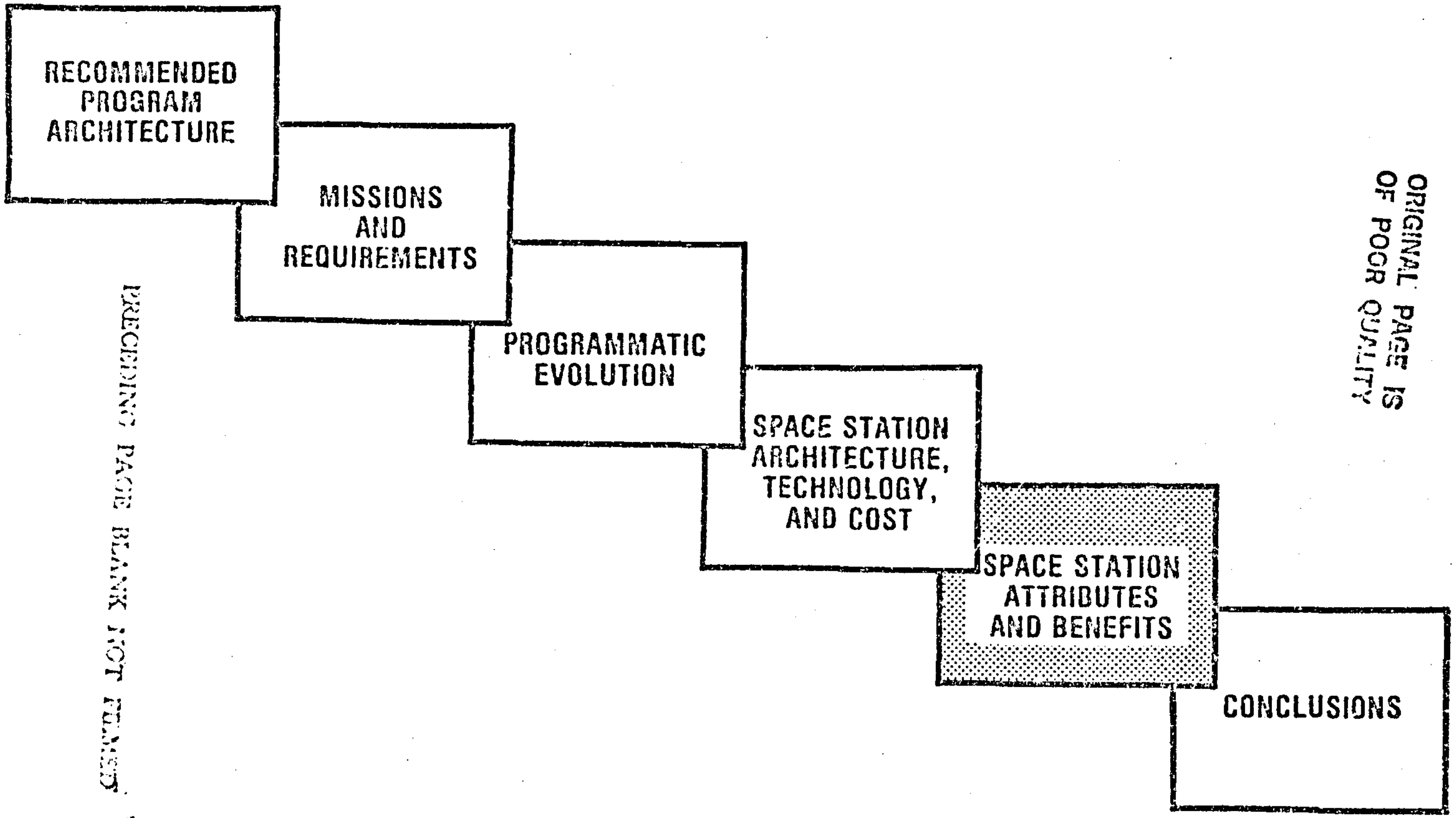

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SPACE STATION ATTRIBUTES AND RESULTING BENEFITS

The three major areas of benefits of the station are lower user cost, better performance, and mission enablement. this chart shows how the Space Station attributes relate to these benefit areas.

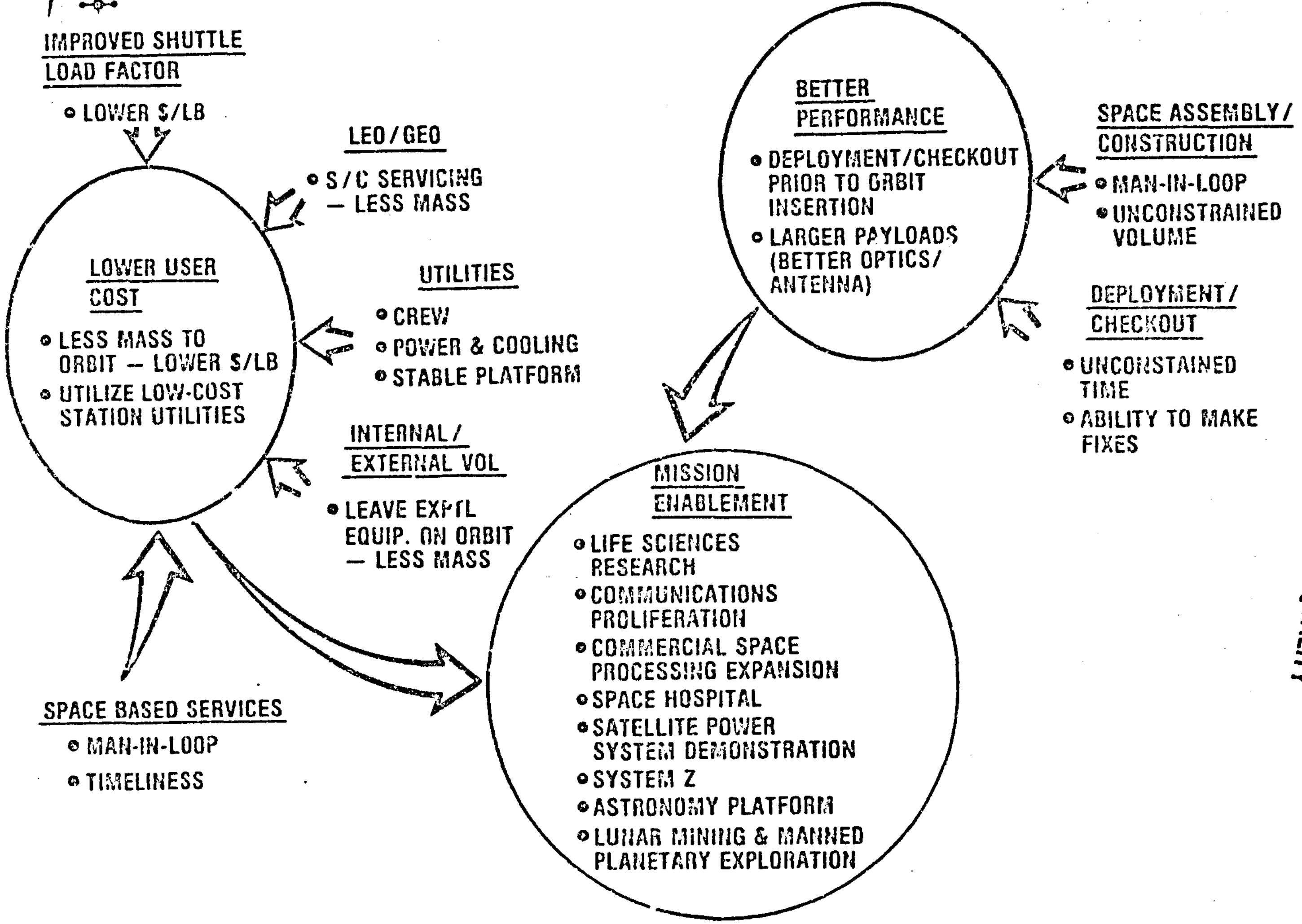
Better performance can be obtained because of the station capability to deploy and checkout payloads prior to placement in their mission orbit. In addition, if a malfunction occurs, it may be possible to make fixes at the station rather than having to refly the entire payload. The station capability to assemble and construct payloads will lead to larger payloads, including larger optics and larger antennas.

User cost is reduced by a number of factors. Space-basing of mission services for the OTV results in a decoupling of the payload, stages, and propellants. This results in average cargo load factors of about 1.0 for Shuttles going to the station. LEO and GEO servicing from the station also reduces user costs since it allows the spacecraft to have extended life. Additionally, mission equipment can be changed out to take advantage of technology improvements. Since man is on orbit permanently, the services can be provided in a timely manner without the need for manifesting into the orbiter. Utilities provided by the station (crew, power, and stable platform) are obtained at a very low cost compared to other alternatives. The ability to leave equipment on the station is very important to reducing user costs as compared to Shuttle sortie missions, where the experiment equipment needs to be carried up and down. In the space processing research area, the experiment equipment is greater in mass than the experiment mass.

A combination of lower user cost and better performance, as well as the uniqueness of a permanently manned facility lead to mission enablement. Some of the areas of enablement are shown on this chart. Enablement of system Z and, if needed, an astronomy platform arises from the use of station elements as the basis of a platform (power module and payload support assembly).

SPACE STATION

SPACE STATION ATTRIBUTES AND RESULTING BENEFITS . . .



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USER COST BENEFITS--POST 1994

The next two charts compare the cost of several Space Station services for alternate ways of providing the service.

As shown, LEO placement costs through the station are 26 to 45 percent less than if there were no station. Use of the space-based OTV saves from 0 to 40 percent for the small 1,400-pound GEO communication spacecraft. The 40 percent savings occurs when three are deployed on the OTV at one time. Savings of 48 to 55 percent occur when the OTV is compared to a Shuttle-launched inertial upper stage (IUS) first-stage and a 30-percent savings occurs when the OTV is compared to the Centaur F for large 12,000-pound spacecraft.

Cost savings are also shown for LEO and GEO servicing. LEO savings range from 34 to 39 percent, dependent upon the number of spacecraft services at one time. A 38-percent savings is made for GEO servicing of six spacecraft at one time.

Space processing receives the most benefit. As shown, the processing cost of pharmaceuticals at the station is small compared to the cost of the material that is being processed. A 15-day Shuttle Spacelab sortie results in a processing cost that is greater than the value per pound of the processed material. Enormous cost savings also occur for space processing research on the Space Station.

Finally, attached science is also exposed at a very low cost per day of exposure compared to an extended duration orbiter.

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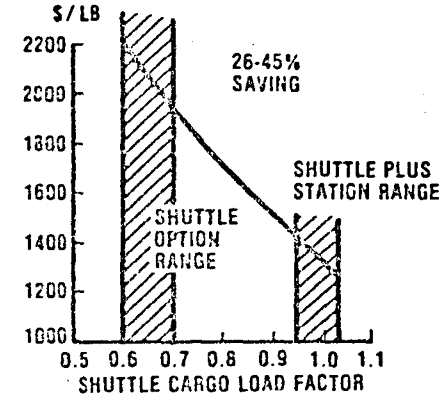
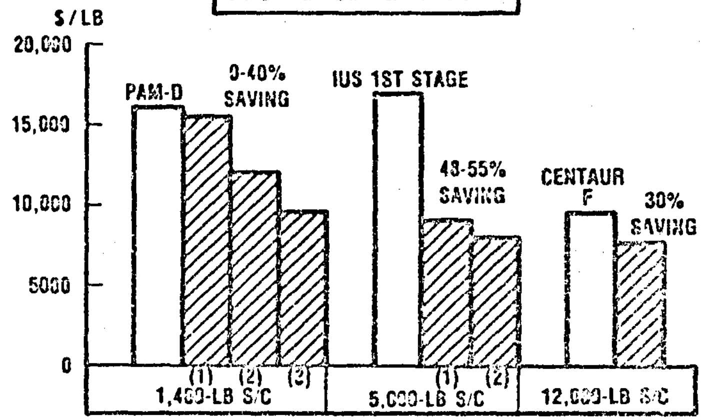
SPACE STATION

USER COST BENEFITS — POST 1994 . . .

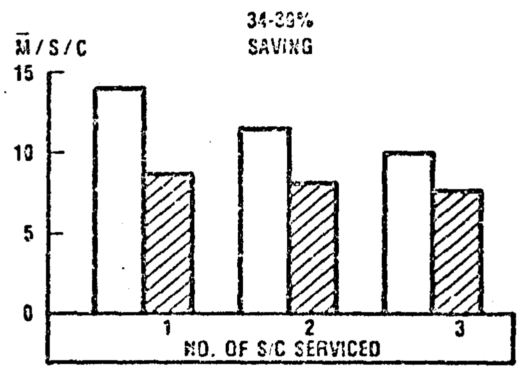
LEO PLACEMENT COST



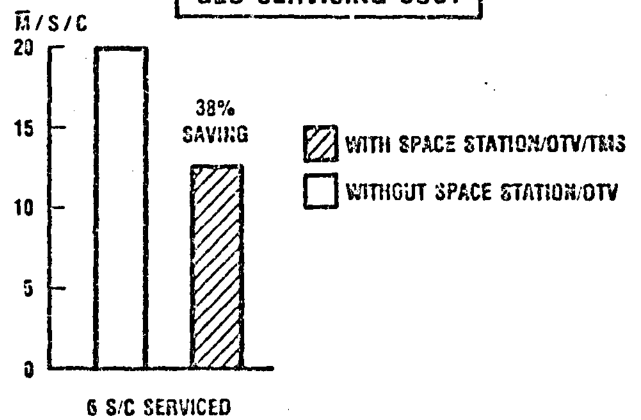
GEO PLACEMENT COST



LEO SERVICING COST



GEO SERVICING COST



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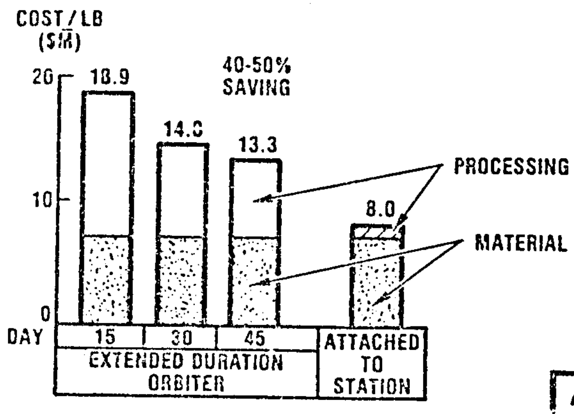
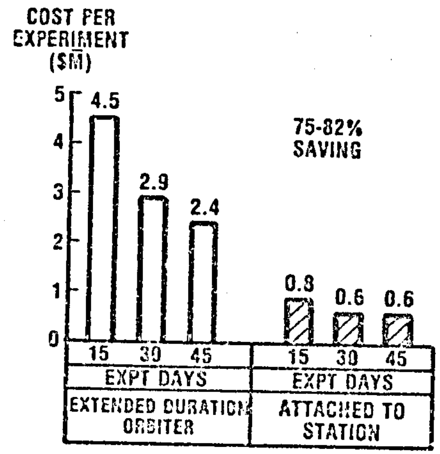
SPACE STATION

USER COST BENEFITS — POST 1994 ...

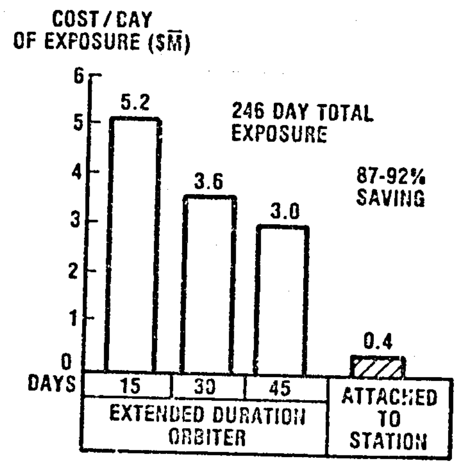
SPACE PROCESSING PRUDUCTION PHARMACEUTICAL



SPACE PROCESSING RESEARCH



ATTACHED SCIENCE (SIRTF)



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SUMMARY OF MISSION MODEL LEVEL IMPACTS

The following two charts summarize the impact that the mission model level (low, medium, and high) has on the number of missions and mission mass, Space Station crew hours, number of Shuttle flights, and total space support system program cost. All of these data are for operations from the year 1991 to 2000.

As might be expected, the trend in both number of missions and mission mass is to increase from low to high. The increase in the ratio of mass from low to medium and from medium to high is 1.68 and 1.74, respectively, as compared to the ratio of number of missions, which is 1.30 and 1.34, respectively. Therefore, the average payload mass increases from low to medium and from medium to high.

The Space Station crew hours are for the entire ten-year period. The low model requires only a four-man station; whereas, the medium model requires an initial four-man station that grows to eight men in 1994. The high model increases the growth requirement to ten men.

The number of Shuttle flights without the station is nearly double that of those with the station for all mission model levels. Operation costs also generally follow this trend. Most of the additional flights for the no station case are attributed to the need to accomplish the space processing missions. Other inappropriate missions were removed to determine the mission model when there is no Space Station.

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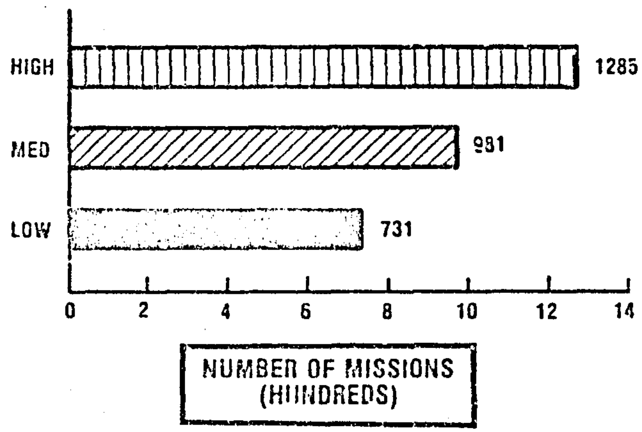
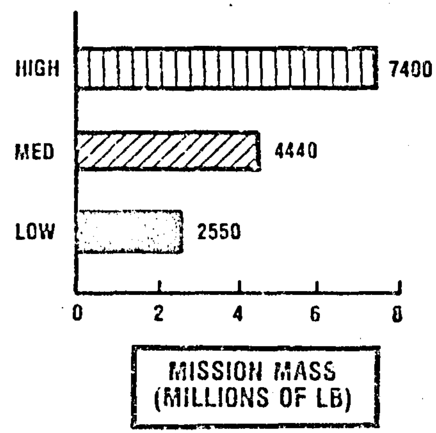
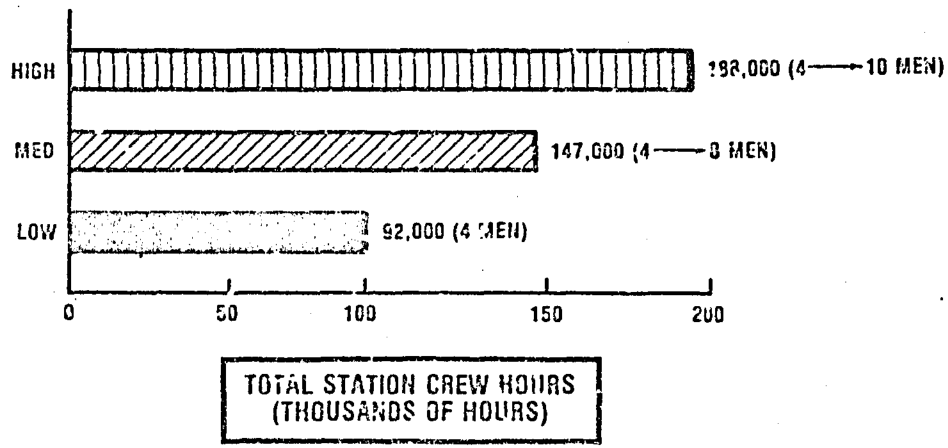
SPACE STATION

SUMMARY OF MISSION MODEL LEVEL IMPACTS ...







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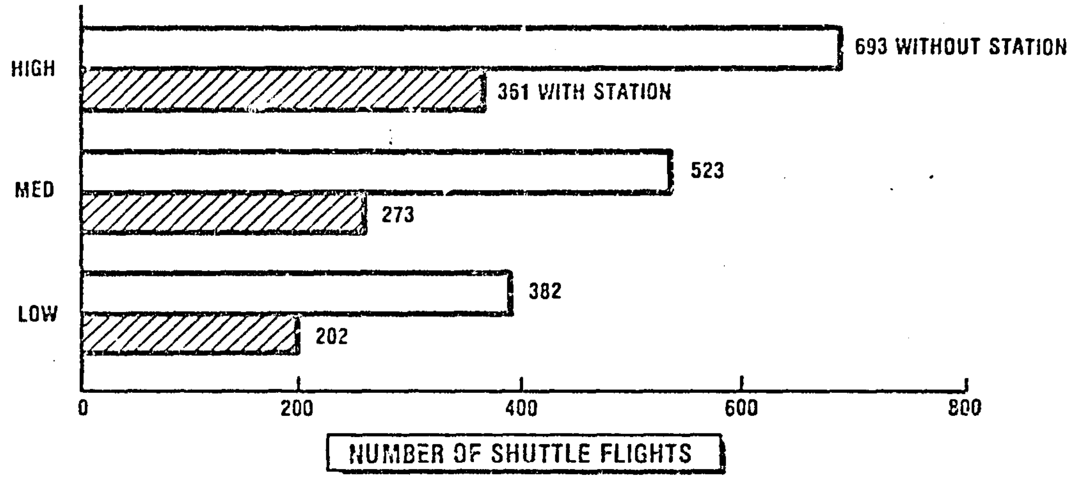
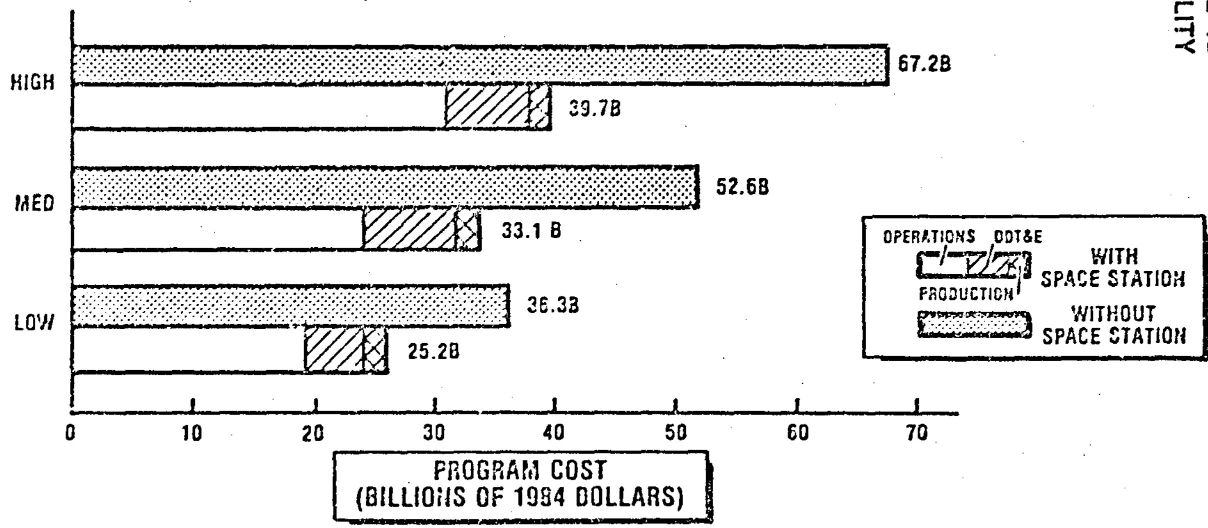
SPACE STATION

SUMMARY OF MISSION MODEL LEVEL IMPACTS (Cont) ...





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IMPACT OF SPACE STATION ON MISSION MODEL

Two mission models were developed to show the impact on the mission areas because of a Space Station. This chart summarizes some of the major impacts.

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SPACE STATION

IMPACT OF SPACE STATION ON MISSION MODEL...

MISSION AREA	WITH CURRENT SYSTEM & TMS	ADD STATION & OTV
DOD	• SAME PROGRAM THRUST AS WITH STATION • NO GEO SERVICING (151 FLIGHTS)	• ADD GEO SERVICING (130 FLIGHTS)
NASA SCIENCE & APPLICATION	• CONSTRAINED IN ANTENNA & OPTICS SIZES • HIGHLY CONSTRAINED LIFE SCIENCES — SORTIE MISSIONS (71 FLIGHTS)	• ROBUST LIFE SCIENCES PROGRAM • ASTRONOMY & SYSTEM PLATFORMS ARE STATION DERIVATIVES (42 FLIGHTS)
NASA TECHNOLOGY DEVELOPMENT	• CONSTRAINED PROGRAM • LESS AMBITIOUS OBJECTIVES SUPPORTED — SCIENCE & APPL TECH — SPACE STATION TECH (2 FLIGHTS)	• MORE AMBITIOUS OBJECTIVES SUPPORTED — GEOSYNC MULTIFUNC COMM PLATFORM — GLOBAL ENVIRONMENT MONITORING SYSTEM — LUNAR OPERATIONS BASE — MANNED MARS MISSION (4 FLIGHTS)
COMMERCIAL COMMUNICATIONS	• NO MULTI—USER SYSTEMS • NO SERVICING (60 FLIGHTS)	• ADD MULTI-USER SYSTEMS • MORE TRANSPONDERS (47 FLIGHTS)
COMMERCIAL SPACE PROCESSING	• CONSTRAINED RESEARCH • ELECTROFOCUSING PRODUCTION ELIMINATED (13 FLIGHTS)	• NO LIMITS TO RESEARCH • ELECTROFOCUSING PRODUCTION ON STATION (11 FLIGHTS)
TOTAL FLIGHTS	297	273 (39 FOR STATION ASSEMBLY & LOGISTICS)

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SUMMARY OF BENEFITS

This chart summarizes the quantifiable benefits to the Space Station users and to the nation as a whole. These are shown in billions of 1984 dollars, discounted at 10 percent per year, and brought to present day value in 1986. Out of the total benefits of $17.3B to the users, $6.9B, or 40 percent, are because of space processing, with approximately 20 percent being caused by, respectively, science and applications, commercial communications, and national security.

The total benefits to the nation are $94.9B, or about 5.5 times the benefits to the users. This high factor generally reflects the high technology, "never-been-done-before" nature of the Space Station's new missions.

As for the users, the largest benefit area is space processing, with $36.5B, or nearly 40 percent of the total. There are roughly equal contributions in the remaining four areas.

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SUMMARY OF BENEFITS, $B ('84) . . .

	TO USERS	TO NATION
SCIENCE & APPLICATIONS	3.2	11.4
SPACE PROCESSING	6.9	36.5
COMMERCIAL COMMUNICATIONS	3.5	17.0
NATIONAL SECURITY	3.3	15.3
SPACE TECHNOLOGY	0.4	14.7
TOTAL	17.3	94.9

- DISCOUNTED AT 10% PER YR
- 1986 PRESENT YEAR VALUE

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BENEFITS VERSUS INVESTMENT

The ultimate usefulness of a benefits analysis is for the nation to decide whether the benefits to be derived are worth the investment that has to be made to obtain them. It is not sufficient for the benefits to exceed the investment; they should exceed the investment by a large enough margin so that the project can compete successfully with alternative uses of scarce resources. The proper comparison is between the dollar value of the quantifiable benefits to the nation derived from the Space Station, discounted to present day value; and the investment that must be made by the government, similarly discounted, to cause these benefits to happen; i.e., the DDT&E and production costs for the initial and growth Space Station and OTV. Operational costs of the Space Station and OTV are reimbursable to the government by the users, and are therefore not included in the investment.

This comparison is shown on this chart. The benefits are broken down as cost savings and value added, and the investment into Space Station and OTV.

The comparison shows a favorable relationship (with discounted benefits to the nation of \$94.9B) for a discounted investment of \$7 6B. The cost savings to the nation of \$13.6B by themselves exceed the investment by a factor of 1.8, although they are spread out between a variety of government and private sector users. The overall benefits to investment ratio, for the quantifiable benefits only, is 12.5. This is an attractive ratio for any new venture, either in the government or in the private sector, and can be expected to compete favorably with other potential uses of the same investment.

The decision on the value of the Space Station must take into account two further considerations, both of which make the Space Station more attractive.

1. Only the quantifiable benefits through the year 2000 have been accounted for. Since the Space Station and OTV will probably be operational to about 2010, additional potentially large benefits, will accrue (although their present day value in 1986 is reduced by the discounting process).

2. There are additional nonquantifiable benefits because of the presence of the Space Station. These may, in fact, be the dominant benefits.

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BENEFITS vs INVESTMENT ...

BENEFITS TO THE NATION		INVESTMENT BY U.S. GOVERNMENT	
• COST SAVINGS	$13.6B	• SPACE STATION	$6.8B
• VALUE ADDED	$81.3B	• OTV	$0.8B
	$94.9B		$7.6B

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BENEFITS / INVESTMENT = 12.5

MAJOR USER COMMENTS ON ROCKWELL ARCHITECTURE

Before initiation and during the study, several interactions were accomplished in all potential user areas. This chart summarizes user comments at the completion of the study. These comments are based on their review of mission models, accommodation modes, requirements, and benefits.

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SPACE STATION

MAJOR USER COMMENTS ON ROCKWELL ARCHITECTURE ...

SCIENCE & APPLICATIONS

- MISSION MODEL REASONABLE FORECAST OF S&A ACTIVITY
- ISSUES REMAIN ON SYSTEM Z ORBITAL LOCATIONS
- INCOMPATIBILITIES IN ASTRONOMY INSTRUMENT POINTING MAY REQUIRE TWO SMALL PLATFORMS

NATIONAL SECURITY

- CONCURRENCE IN ALL AREAS
  - MISSION MODEL, LINKAGE WITH INFRASTRUCTURE, & FRANGIBLE OPERATIONS CONCEPT

COMMERCIAL COMMUNICATIONS

- SPACE BASED OTV CONCEPT DESIRABLE
  - SINGLE STAGE vs PKS STILL NEEDS STUDY
- MISSION MODEL COMMENTS RANGE FROM TOO LOW TO TOO HIGH
- MASS DISTRIBUTION OF SPACECRAFT ABOUT RIGHT
  - SOME PLATFORMS COULD GROW > 12,000 LB
- STATION ASSEMBLY, DEPLOYMENT, & CHECKOUT DESIRABLE
- GEO SERVICING OF LARGE SATELLITES & PLATFORMS ADVANTAGEOUS

COMMERCIAL SPACE PROCESSING

- MISSION MODEL LEVEL ACCEPTABLE
- ACCOMMODATION OF MISSIONS ACCEPTABLE
  - SOME QUESTION REGARDING CRYSTALS G-LEVEL
- PRODUCT AREAS APPROPRIATE FOR COMMERCIALIZATION
- NEED STATION TO ENABLE COMMERCIALIZATION

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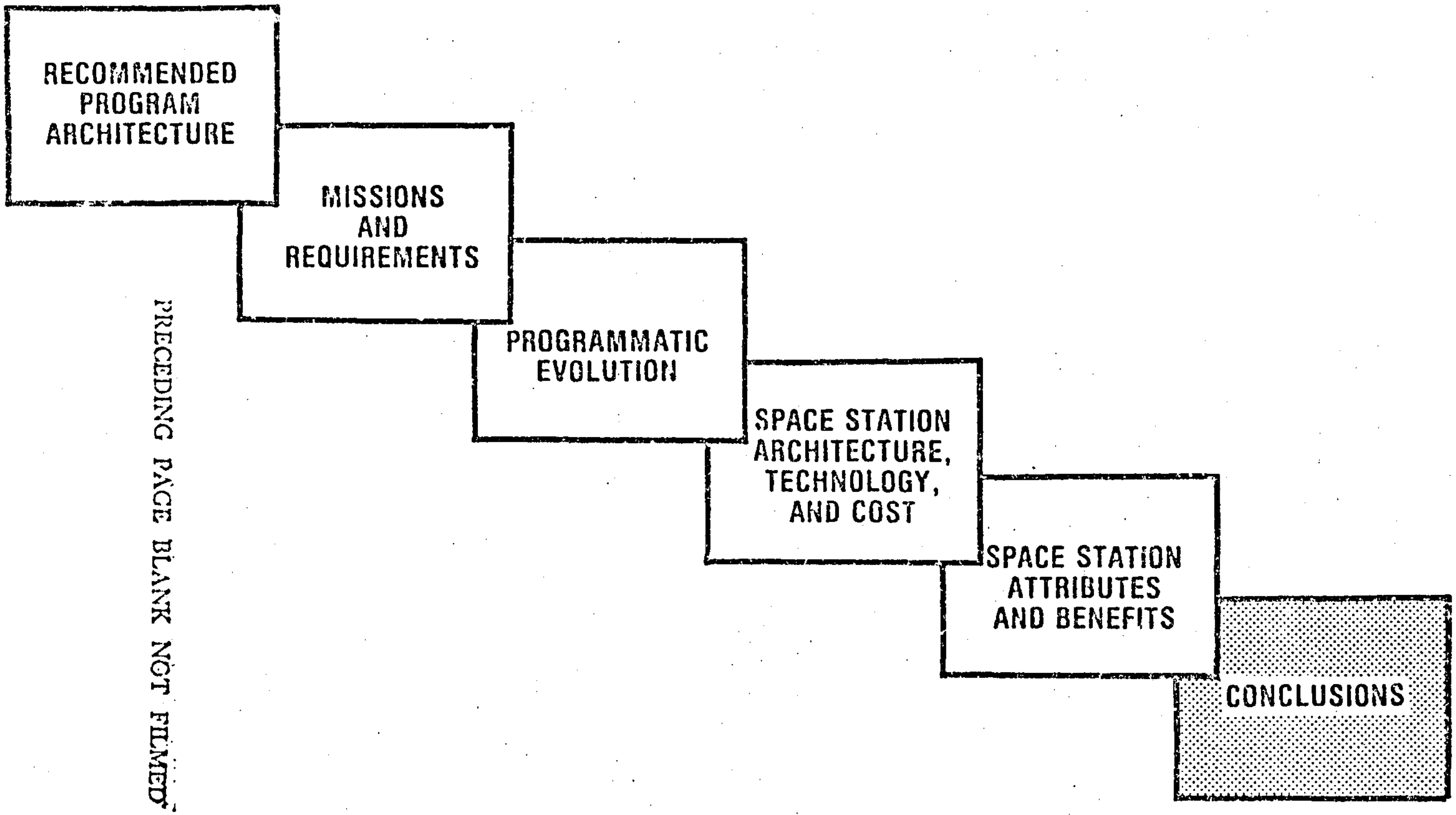

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WHY STATION?

This chart summarizes some of the most important reasons for having a Space Station. These are separated into three main categories: mission payload, operations, and economic factors.

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WHY STATION?...

MISSION PAYLOAD

- REMOVES SIZE CONSTRAINTS
- DECOUPLES PAYLOAD, OTV, & FUEL
- ENABLES CONTINUOUS SERVICING CAPABILITY — LONGER LIFE
- PERMITS DEPLOYMENT & CHECKOUT

OPERATIONS

- UNCONSTRAINED MISSION TIME
- CONTINUOUS CREW/OPERATOR AVAILABILITY
- INCREASED AVAILABILITY FOR DOWN CARGO
- COST EFFECTIVE — PAYLOAD MASS EXPOSURE
- COST EFFECTIVE — PAYLOAD ENERGY

ECONOMIC FACTORS

- MAXIMIZES STS LOAD FACTOR
- PERMITS SPACED-BASED REUSABLE SYSTEMS
- ENABLES MORE COST-EFFECTIVE SPACE PROCESSING

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CONCLUSIONS

This chart summarizes the major conclusions of the study, which have been previously explained in greater detail. The conclusions are presented in three major categories: mission definition, system architecture, and benefits.

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SPACE STATION

CONCLUSIONS . . .

MISSION DEFINITION

- LARGE UNCERTAINTY EXISTS IN SPACE PROCESSING MISSION AREA
- USERS SLOW TO RESPOND TO POSSIBLE CHANGES IN THEIR MISSION EQUIPMENT & S/C DUE TO NEW SUPPORT SYSTEMS

SYSTEM ARCHITECTURE

- STATION LOCATED AT 28° INCLINATION PROVIDES SERVICES TO ALL USER AREAS —
  - PROVIDES LOWEST COSTS TO USERS
- INITIAL 4-MAN STATION IN 1991 GROWING TO AN 8 MAN STATION IN 1994
  - TWO 4-MAN STATIONS ATTRACTIVE & NEEDS MORE STUDY

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CONCLUSIONS (CONT) . . .

SYSTEM ARCHITECTURE (Cont)

- TMS SPACE-BASED WITH INITIAL STATION & PERIGEE KICK STAGE, REUSABLE CRYOGENIC OTV SPACE-BASED WITH GROWTH STATION
- Z & ASTRONOMY PLATFORM DERIVITIVES OF STATION IN 1993 & 1995 RESPECTIVELY
  - PLATFORM DERIVATIVE NEEDS BETTER DEFINITION

BENEFITS

- SPACE STATION AT 28° INCLINATION PROVIDES SIGNIFICANT BENEFITS TO ALL MISSION AREA
  - INDIRECT BENEFIT TO SYSTEM Z IN HIGH INCLINATION & ASTRONOMY PLATFORM
- THE MOST IMPORTANT SPACE STATION BENEFITS ARISE FROM FUTURE MISSIONS ENABLEMENT
- SIGNIFICANT COST REDUCTIONS OCCUR FOR ALL SERVICES
  - SPACE STATION MAY ENABLE A VIGOROUS COMMERCIAL SPACE PROCESSING PROGRAM

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